THE HYDROSTATIC
SYSTEM OF TREES

D. T. MACDOUGAL

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BY

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CONTENTS.

# THE HYDROSTATIC SYSTEM OF TREES.

By D. T. MacDOUGAL.

## CONCLUSIONS AND THEORETICAL CONCEPTIONS UPON WHICH PRESENT WORK WAS BASED.

It is obvious that any definite knowledge of the "ascent of sap" or of any of the major movements of liquids in large plants must rest upon a comprehension of the hydrostatic conditions as a whole.

The separate factors are doubtless most easily to be measured in large shoots, such as trees, and less advantageously in vines. It has been made abundantly evident, however, that fragmentary studies on such separate phenomena, as root-pressure, "negative" pressure, sap conduits, or any segregated translocatory phenomena may not be expected to furnish the basis of any serious advance in knowledge of the complex hydrodynamics of trees.

The hypotheses which have been advanced in explanation of the movements of sap beginning with the presentation of the conclusions of Grew to the Royal Society of London in May 1671, and the submission of a manuscript by Malphigi on the same subject in December of the same year are many.[1] Actual advance since the experiments of Stephen Hales published in 1727 has been at the cost of an enormous total of labor and experiment. Much of the voluminous literature is devoted to criticism and to the delimitation of the possibilities.

The proposals of Dixon as to the maintenance of a cohesive meshwork column of water in the wood, from the roots to the menisci in the transpiring walls of living cells in the leaves, is to be named as an enduring conception and as a feature of the hydrodynamics of the plant which has been confirmed by all results in the present paper.

It is unnecessary to make a comprehensive discussion of the work of Strasburger on the anatomy, arrangement and action of conduits, or to review the work of Ewart in this place. Articles by Ursprung [2] and by Renner [3] and others are admirable examples of discussions of certain phases of the hydrodynamics of the plant.

It is notable that no satisfactory delineation has been made of the manner in which the leaf products are moved with adequate speed in the required volume toward the bases of stems. The present paper includes results upon which certain phases of sap pressure are explainable. Not all "root-pressures" are accounted for, however.

[1] Grew, N. The anatomy of plants. 1682. See Preface and p. 26, Book 1, Malphigi, Opera Omnia. 1687.

[2] Ursprung, A. Einige Resultate der neusten saugkoftstudien. Flora, 18–19, 566, 1924–5.

[3] Renner, O. Die Porenweite der Zellhäute in ihrer Beziehung zum salftsteigen. Ber. d. deut. Bot. Ges., 43, 207, 1925.

The state of the problem described is one in which the separate researches in the field have not been so closely joined as to form a good foundation for general conclusions. Results from different types of stems have been unwarrantably compared. Manometric measurements of "sap pressures" have been made with no definite observation of the structures or tissues affected by the bores or excisions, so that at the present time data as to this topic constitute a hopeless hodgepodge. The writer acknowledges no obligation to arrange these in order or to correlate the figures with those given on the following pages.

The present approach to this subject has been made on the basis of studies of hydration phenomena of dead and living cells in which changes in volume were measured by the auxograph; on the nature of the reversible variations in volume of tree-trunks; on phenomena of growth as recorded by the dendrograph, and upon extensive experiments dealing with exudation pressures and suction force in vines, columnar cacti, oaks, pines and walnut trees. The extent of this work is described in various publications since 1914.

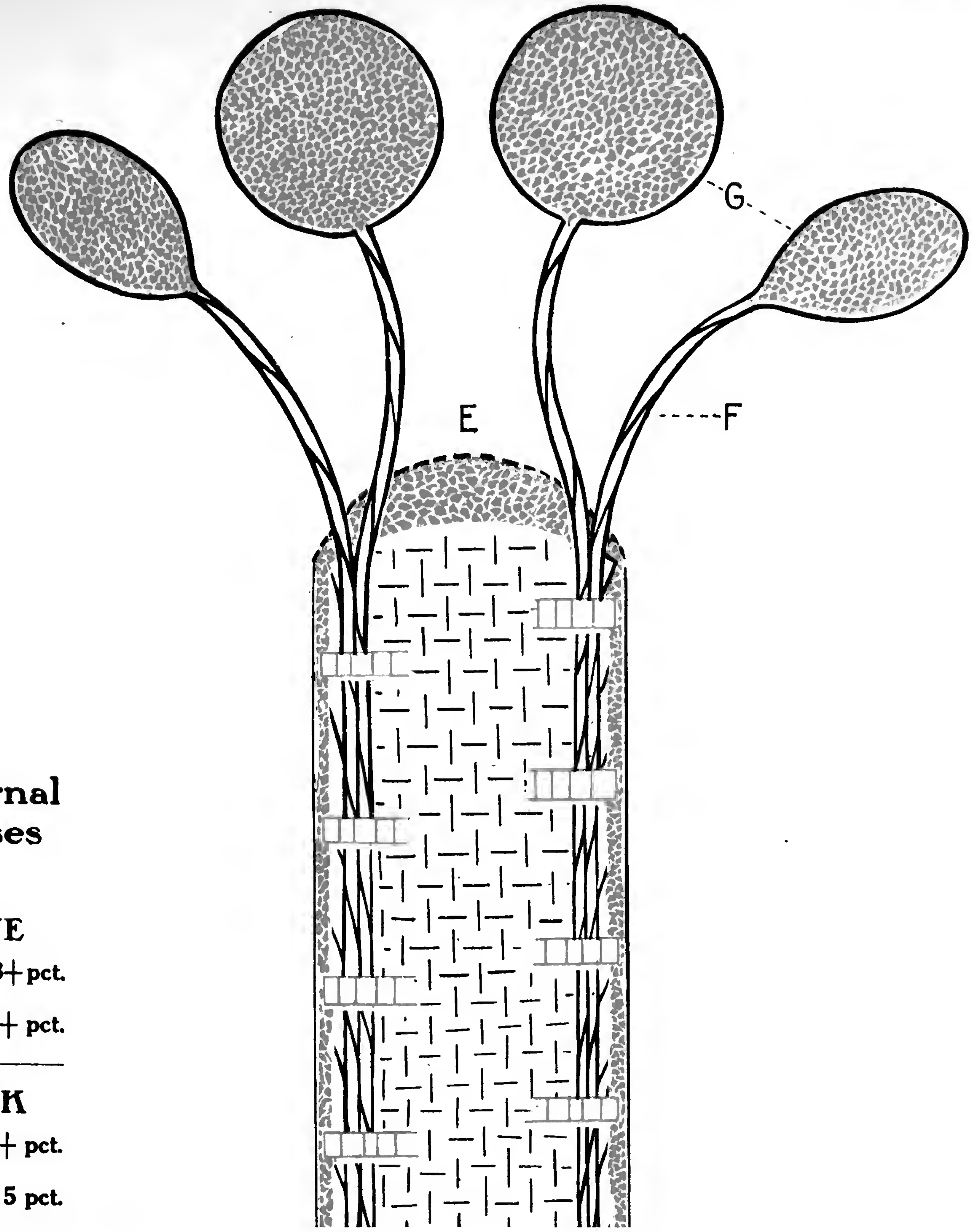
The general conclusions reached may be profitably anticipated to some extent for the purpose of presenting a unified conception of the large leafy plant as a hydrostatic system. This was attempted recently in a previous paper.[1] Some important modifications based upon results in the present paper are now proposed. The principal advances concern the body of gas in the older wood; the capillary extension of the water column in this wood; the strictness of conduction of solutions in the outer layers; or more briefly stated, the localization of mechanical factors and of the physiological action affecting movements of solutions.

The following features are to be taken into account in my comprehensive study of the hydrostatic system of the higher plants.

(*A*) Solutions enter the roots of plants via the root-hairs and through the endodermis with its turgid cells and heavy rigid radial (transverse and longitudinal) walls. The tangential walls are more permeable. Water of the soil-solutions is drawn through the endodermis whenever the osmotic value of the elements internal to the endodermis is greater than that of the cortex, root-hairs and soil-solutions, in a manner but little affected by the superior turgidity of the endodermal sheath. Ions of soil-salts pass into the root at a rate and in a manner determined by their specific mobilities, effects on the colloidal plasmatic layers and implied interferences or "antagonistic" effects.

Between the arrival of water, soil-salts and sugars, in the living cells internal to the endodermal sheath, and the passage of the solution into the dead conduits of the roots communicating with the recently formed wood is some form of exudative or secretive action, not yet perfectly

[1] MacDougal, D. T. Absorption and exudation pressures in plants. Proc. Amer. Phil. Soc., 64, 102–130, 1925.




**Internal Gases**

**PINE**

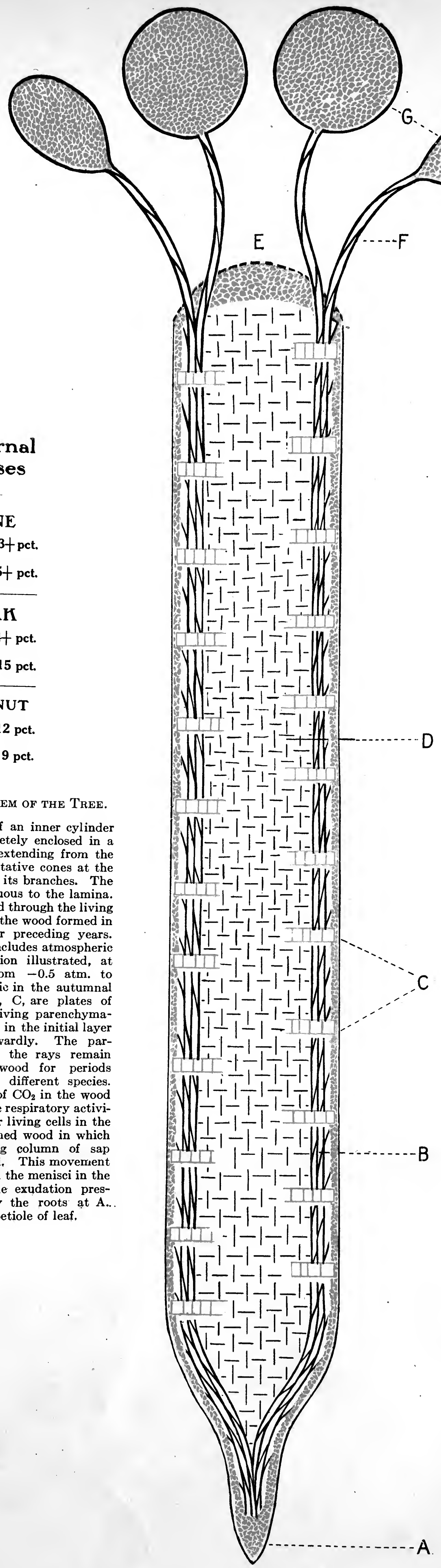
$CO_2$, 3+ pct.

$O_2$. 15+ pct.

**OAK**

$CO_2$. 4+ pct.

$O_2$. 15 pct.




## Internal Gases

**PINE**

$CO_2$, 3+ pct.

$O_2$, 15+ pct.

**OAK**

$CO_2$, 4+ pct.

$O_2$, 15 pct.

**WALNUT**

$CO_2$, 12 pct.

$O_2$, 9 pct.

HYDROSTATIC SYSTEM OF THE TREE.

The tree consists of an inner cylinder of older wood, completely enclosed in a layer of living cells extending from the root caps to the vegetative cones at the tips of the stems and its branches. The living layer is continuous to the lamina. The leaves are inserted through the living layer to connect with the wood formed in the previous year, or preceding years. The older wood, D, includes atmospheric gases of a composition illustrated, at pressures varying from −0.5 atm. to something atmospheric in the autumnal condition. The rays, C, are plates of short tracheids and living parenchymatous cells terminating in the initial layer in the cambium outwardly. The parenchymatous cells of the rays remain alive in the older wood for periods of varying length in different species. The high proportion of $CO_2$ in the wood may be ascribed to the respiratory activities of these and other living cells in the wood. B, newly formed wood in which the upwardly moving column of sap under tension is found. This movement is due to the pull from the menisci in the leaves, G, and to the exudation pressure when shown by the roots at A. E, growing point, F, petiole of leaf.

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understood and not to be passed lightly. The continuous and advancing zone of maturity in the wood and conduits frees some material from the osmotic mechanism of living cells. This material attracting some water would set up a head of pressure which would tend to force solution up through the stems, where it might be measured as "root" or exudation pressure. In addition living cells, which have a common wall with dead conduits or tracheids, might show an increased permeability on this part of their periphery which might result in long-continued excretion of water into the conduits. Such specialized permeability might, for example, result from the displacement of calcium in sectors of the plasmatic layers or membranes by potassium or sodium. It is well known that alterations of this kind in root-hairs allow the passage or leakage of sugars, amino-compounds or large ions at a high rate.

This excretory action is one in which each living parenchymatous cell would pass through a definite cycle of hydration, accompanied by expansion followed by contraction and loss of contents into the conducting tracts, followed by a partial or total collapse. Such action has been studied in the thick cortical layers of the tree cacti where the cells abutting on bores first absorb water introduced through a manometer setting up a measurable suction. Later the increased permeability of the cell layers allows the osmotic potential to be expressed as exudation pressures, which must be in every essential identical with the pressures set up in roots. Whether or not such pressures may be shown by stem-bases and attached root-systems may be determined by many factors including such anatomical features as the amount and character of the parenchyma in the central cylinder of the roots.

(*B*) The freely moving liquids of the stem move upwardly most abundantly in the recently formed wood layers to which the leaves are attached terminally. In the Monterey pine the leaves are retained a second or third year, and are formed directly on the axes of nodes of the terminal. The sap stream in such cases follows the second, third and fourth layers on the older parts of the stem, and the first, second and perhaps the third in the terminal parts. The layers may not be so strictly defined in the oak, walnut or other trees examined. The presence of extensively connected tracheæ in the wood modifies the pattern somewhat.

In any case solutions may move radially chiefly through the rays, the tracheids of which are not to be taken as emptied of colloidal contents so soon as the longitudinal elements. Circumferential or tangential movement is also slow, as will be shown by the results of pumping sap from bores in the ends of trunks.

(*C*) The cambium of a tree constitutes a continuous layer, several cells in thickness over the entire plant, and is pierced only by the leaves. These organs interpose living cells between the atmosphere

and the wood, although connection prevails between the loosely arranged parenchyma of the leaves and the cortex of stems. The cortex communicates by lenticels and rifts directly with the atmosphere. Samples of the gases taken by suction from an entire cut end of a stem may therefore be expected to show a composition not widely different from that of the air.

The recently formed wood carrying the column of sap, in which the elements of the rays are alive or present themselves as colloidal masses, forms a second enclosure of the woody column of a tree, through which diffusion of gases or liquids may take place but slowly. That such enclosure is practical and effective is plainly evident from the results of the analyses of the gases taken from the central cylinder of the oak, pine and walnut, which in the autumnal condition are in proportions widely different from those of the surrounding atmosphere.

An active respiration in the inner living cells or rays would cause an increase in the proportion of carbon dioxide, and would tend to increase the amount of diffusion from the central cylinder, with consequent lessening of pressure, a matter to which attention was called in 1901.[1] An increased proportion of carbon dioxide in the wood would also cause a higher suction pressure to show in manometers attached to bores or stems by tubes filled with water.

Both composition of the gases in the woody cylinder and the state of pressure may vary widely. No recent contributions to this subject have been made, but comprehensive recapitulations are given by Pfeffer,[2] and by Palladin and Livingston.[3]

The security with which the enclosed air-body is held and its varying composition render it of great importance to the hydrostatic system, in which it performs a mechanical function comparable to that of the air-chamber in force and suction pumps which the plant constitutes. Early in the course of the experiments described in the present paper it was found that in all manometric work the nature of the connection of the bore or of the leading tube of the pressure gage was of great importance. Gages inserted in the cortex, in the water-conducting layers, or which connected with all three naturally gave diversified results. The attempt has been made to carry out more definite tests and to correlate results obtained from different parts of the plant machine.

(*D*) Positive or exudation pressures have been observed in stems by instruments attached to bores and to stumps for extended periods. Such action may be due to hydration phenomena as described in (*A*). Liquids may be forced to carrying heights in stems by such action. Transpiration of water from the minute menisci in the walls of tran-

[1] MacDougal, D. T. Practical text-book of plant physiology. Page 189, 1901.

[2] Movements and pressure of internal gases, in *Physiology of Plants*. Trans. by A. J. Ewart, vol. 1, 199–206, 1900.

[3] Movements of gases, in *Palladin's Plant Physiology*. Ed. by B. E. Livingston, 118–121, 1918.

spiring leaf-cells sets up a tension in the column of water which extends downward in the trunk, and it is this pull which constitutes the principal lifting force in the ascent of sap. The increased loss of water and the attenuation of the column is followed by a shrinkage or contraction of the cambium and living layers of cells and of the outer layers of wood in a manner characteristic of the species as shown by the dendrographic record. Concurrent variations in pressure are shown by water-filled gages connecting with the sap-filled layers, the central cylinder, and with the cortex, but the correlations between the variations of pressure measured by the manometer and of variations in diameter have been made for two or three phases only.

(*E*) Various rôles have been ascribed to living cells in attempted explanations of the mechanism of movement of solutions in stems. The cambium external to the wood has not been taken as an active factor beyond its action in the production of new elements and in the maintenance of a complete layer of cells, which effectually stops capillary movements radially and is only slowly permeable to the gases of the central cylinder.

The tracheids of the conifers and also the tracheæ of dicotyledonous trees are in intimate connection with the living cells of the rays and with the parenchyma which sheathes the vessels. The sap stream is, therefore, moving upward in conduits which may be elongated tubes or wood cells intercommunicating by minute perforations, but which are in contact with the sheets or plates of short tracheids and living parenchyma of the medullary rays.

The exchanges between the two kinds of elements may be very complicated. Ions of salts coming from the soil would pass into the rays and other external elements, as into the roots, in a manner determined by their own mobility and specific effect on the cell colloids. Such effects might include marked changes in permeability as a result of which material of almost any kind might be exchanged between the wood and living elements. If these changes were such as cause a contraction of the living cells, liquid would be forced into the wood and might show as root-pressure in a gage attached to a bore in the wood. On the other hand, the osmotic balance might be such that water would be drawn from solutions of low concentration in the wood or vessels and carried across to the cambium. However, this interplay may be balanced, and it is clear that the total thickness of the young wood is lessened at the time of greatest water-loss from the leaves. It seems obvious that the tension set up in the water-column by the pull from the leaves would result in contraction at a time when usually, by reason of the higher temperatures, the suction force of the living cells in the rays and sheaths is greatest. Whether or not such intake of water could proceed to an extent that a condition of high hydration was reached in which water would be lost to the wood cells is a matter yet to be determined. If affirmed it would imply a conjunction of the living

cells of the stem with those of the root in forcing water upward. The results presented do not bear directly on this possibility.

(*F*) Fragmentary results as to the hydrogen ion concentration yield the conception that the cambium is not far from neutral, and that the pH increases inward in the new wood and outward toward the bark. One of the major problems concerns the mechanism of translocation of leaf-products downward through long stems. Conduction through the phloem has long been held as a tentative proposal, but the amount of material moved is such that many difficulties are obvious. The liquid in older wood is under tension and is constantly pulled toward the leaves. The wood of the current year is under such tension only indirectly. If it were allowable to assume that the older wood communicated more freely at the base of the stem, the upward pull in the sap current would operate to draw solutions down through the newer wood. Such a proposal is purely hypothetical, but the arrangement is a possible one and would be an efficient means of transporting material downward through large stems. Something of this kind has been suggested by Dixon.

## MANOMETRIC MEASUREMENTS OF SUCTION AND PRESSURE IN BORES AND STUMPS.

The conception of the hydrostatic system of the tree rests upon the results of observations on the daily reversible variations in trunks, the rate and path of solutions, structures, stomatal action and upon extended use of manometers on trunks of *Pinus radiata, Quercus agrifolia, Juglans major, Sequoia sempervirens, Carnegiea gigantea* and other plants, following on my extensive studies of the variation in volume of living cells in different stages of hydration.

The use of manometers to determine the state of pressure of the gases and liquids in plant stems has been practiced since the time of Hales (1727). The actual connections with the hydrostatic system, a matter of the greatest importance, was established in very few experiments. It is clear that, when a stump of a branch, stem, or root was sheathed in a rubber tube which established connection with a manometer, the variations recorded would be very complex, including the action of the central air-body, the conducting tracts and the cortex. The first does not communicate with the atmosphere in the intact shoot, and the cortex generally does so freely through the lenticels. In some cases the attachment of the rubber tube to a stump would result in a compression of the cortex which would close it for longitudinal conduction of air into the manometer. This can not be assumed in any consideration of previous results.

A second source of error lies in the entrance of air into the manometer system from the wood. The capillary entrance of water from the manometer generally results in the displacement of some gases which collect in the manometer; also, as soon as suction is set up an increased emission of gas results in some cases. A type of man-

ometer was designed so that accumulated air could be eliminated (figs. 2 and 3). It is to be noted in this connection that when a bore is made into the interior air-filled cylinder of a trunk and filled with water that capillary action results, and that some interpretation of the measurements is necessary. Previous results having yielded information by which some of the main features of the gas and water systems illustrated in figure 1 were discernible, plans were made for connecting manometers with various parts of this system in trunks, roots and branches of the Monterey pine (*Pinus radiata*), trunks of oak (*Quercus agrifolia*), and in trunks, branches and roots of the walnut (*Juglans major*) at Carmel, California, in the growing season of 1925. Installation of a suite of instruments was begun in April and observations were continued for 7 months. In order to effect the complete correlation and to procure uniformity in manipulation, nearly all readings and all adjustments of apparatuses in measurement of suction and pressure were made by the author, and as may be seen no period of more than a day or two was allowed to pass without some observations being made. Meteorological records are kept as part of the routine of the Coastal Laboratory, and some references are made to them. It seemed advisable, however, to note conditions of weather in connection with every series of measurements. Temperatures of the newly formed wood in the trunk of the walnut tree were taken by mercurial thermometer with a slender bulb fixed tightly in a cavity made for it. (See fig. 19.) Parallel conditions may be assumed in the other trees.

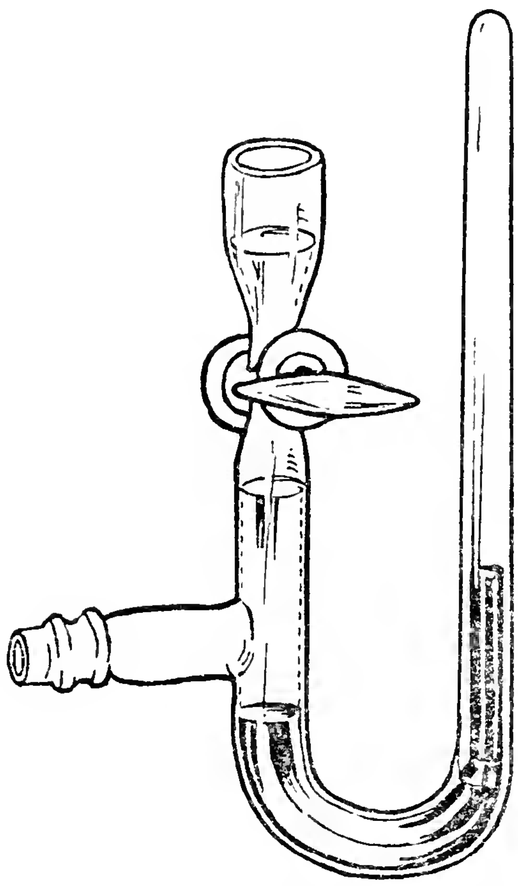


Fig. 2

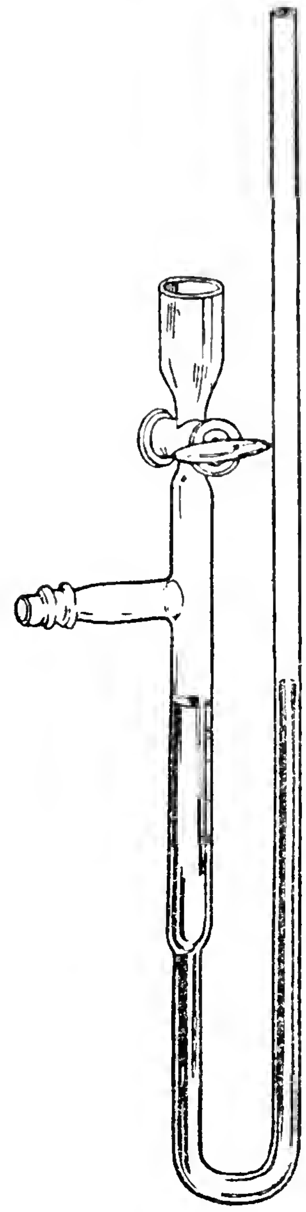


Fig. 3

Fig. 2.—Manometer with closed arm suitable for measuring amount of pressure which may be set up, accompanying an exudation of 1 to 3 ml. of sap. Stopcock and filling funnel are provided to release air drawn from tree and for renewal of watery solution used.

Fig. 3.—Manometer with open end, stopcock and filling funnel for readjustment. The open arm has a bore about 2 mm. in diameter. This type of instrument was used extensively for recording daily variations, being especially useful when changes from less than atmospheric to more than atmospheric pressures, and vice versa, were encountered.

The results of the observations are given on the following pages, those on roots of the pine being taken up first.

## SUCTION IN CUT ENDS OF ROOTS OF MONTEREY PINE.

The terminal end of a root cut 60 cm. from the base of a small tree (*Pinus radiata*, No. XI) was fitted with a manometer with a closed end at first, as illustrated in figure 3, which was later replaced by one as in figure 4.

The tree had grown up slenderly in shade, with a diameter of only 6 cm. near the base, although the stem was over 7 meters in height. The branches were few and small, so that the transpiratory draft on the root system was less than the average. The first fitting of the instrument was made on July 6 and proved to be defective, probably by leakage through the cortical layers. The record is given in Table 1, in which suction is denoted by — sign before the figure denoting the difference between the mercury columns in the two arms of the U tube of the manometer. The actual amount is always slightly greater by the weight of the water in the arm connected with the bore.

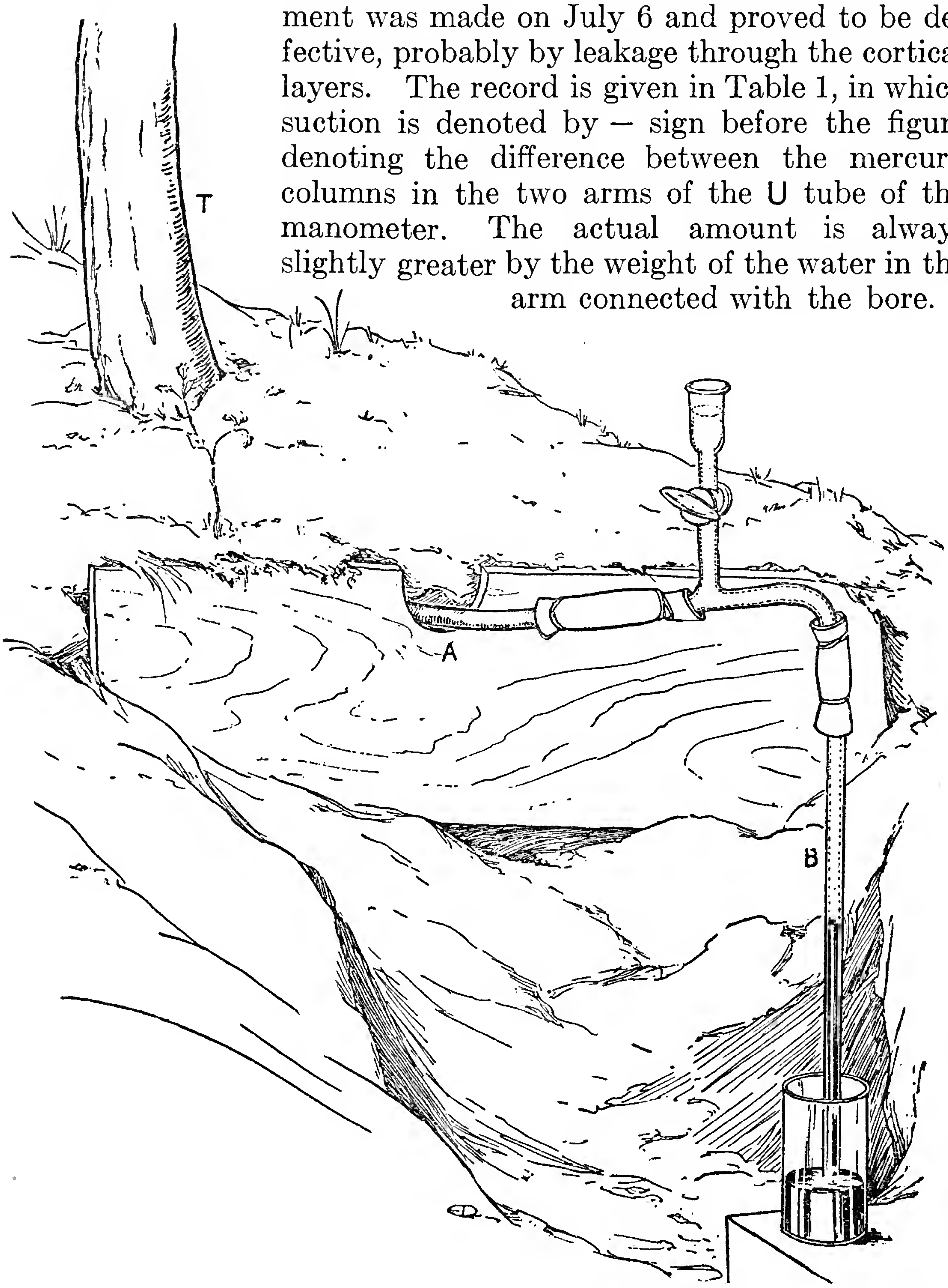



Fig. 4.—Manometer with vertical arm, B, standing in dish of mercury attached to terminal end of cut root, A, of small pine tree. Stopcock and filling funnel serve to release gases drawn out of root and to renew solutions. Attached to Monterey pine No. XI.

TABLE 1.

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 6 | $8^h30^m$ a. m. | ......... | Instrument fitted. |
| | 9 a. m. | − 5 | Clear. |
| | 10 a. m. | − 5 | Do. |
| | 11 a. m. | − 8 | Do. |
| | 6 30 p. m. | − 6 | Overcast. |
| July 7 | 7 a. m. | − 6 | Do. |
| | 9 a. m. | − 6 | Overcast. |
| | 2 p. m. | − 6 | Clear. |
| July 8 | 7 30 a. m. | − 6 | Overcast. |
| | 9 30 a. m. | − 6 | Clearing. |
| | 2 p. m. | − 7 | Clear. |
| | 4 p. m. | − 6 | Overcast. |
| July 11 | 7 30 a. m. | − 6 | Clear. |
| | 11 a. m. | − 6 | |
| | 2 30 p. m. | − 6 | Taken down; surface of root dry and a slice was removed before instrument was refitted. |
| | 3 p. m. | − 18 | Clear and warm. |
| | 4 30 p. m. | − 63 | Do. |
| July 12 | 8 a. m. | −104 | Do. |
| | 10 30 a. m. | −117 | Do. |
| July 13 | 7 30 a. m. | −108 | Air released; set to 0 with stopcock open. |
| | 9 30 a. m. | ......... | Stopcock closed. |
| | 12 m | − 66 | |
| | 3 30 p. m. | −132 | Clear. |
| July 14 | 7 30 a. m. | −115 | Air released; set to 0. |
| | 11 15 a. m. | − 53 | |
| | 2 15 p. m. | − 92 | Alternating sunshine and clouds. |
| July 15 | 7 30 a. m. | −135 | Foggy; air released; set at 0. |
| | 9 30 a. m. | − 10 | Clear. |
| | 1 30 p. m. | − 66 | Do. |
| July 16 | 7 a. m. | −162 | Do. |
| | 11 a. m. | −168 | Clear. |
| | 3 30 p. m. | −162 | Do. |
| July 17 | 7 a. m. | −126 | Air released; set to 0. |
| | 3 15 p. m. | ......... | Stopcock closed. |
| July 18 | 7 a. m. | 42 | Clouds. |
| | 11 30 a. m. | − 66 | Do. |
| | 4 p. m. | − 78 | Do. |
| July 19 | 7 40 a. m. | − 35 | Air out; set to 0. |
| | 10 a. m. | − 14 | |
| | 3 p. m. | − 26 | Clouds. |
| July 20 | 7 a. m. | − 10 | Air released. Taken down, a few mm. sliced from end; reset at 0. |
| | 11 30 a. m. | − 3 | Clouds. |
| | 3 30 p. m. | − 3 | Clear. |
| July 21 | 7 a. m. | − 2 | Overcast. |
| | 11 a. m. | ......... | Do. |
| | 4 p. m. | ......... | Clouds and sun. |
| July 26 | 7 30 a. m. | − 10 | Fog. Had been inactive since the 21st. |
| | 3 p. m. | − 8 | Overcast. |
| July 27 | 7 30 a. m. | − 12 | Do. |
| | 11 30 a. m. | − 12 | Do. |
| | 2 30 p. m. | − 13 | Do. |
| July 28 | 7 a. m. | − 19 | Do. |
| | 11 a. m. | − 18 | Do. |
| | 2 p. m. | − 20 | Clear. |
| July 29 | 7 40 a. m. | − 24 | Overcast. |
| July 30 | 8 a. m. | − 29 | Dripping fog. |
| | 4 p. m. | − 27 | Overcast. |

TABLE 1—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 31 | $8^h$ $^m$ a. m. | − 33 | Overcast. |
| | 11 30 a. m. | − 35 | Sun coming out. |
| Aug. 2 | 3 45 p. m. | − 48 | Clear. |
| Aug. 3 | 7 30 a. m. | − 51 | Overcast. |
| | 11 30 a. m. | − 50 | Clear. |
| | 3 40 p. m. | − 51 | Do. |
| Aug. 4 | 8 a. m. | − 55 | Overcast. |
| | 2 30 p. m. | − 56 | Clear. |
| Aug. 5 | 9 a. m. | − 62 | Fog. |
| Aug. 6 | 2 30 p. m. | − 66 | Clear. |
| Aug. 7 | 9 a. m. | − 69 | Fog. |
| | 4 p. m. | − 72 | Clear. |
| Aug. 8 | 8 a. m. | − 76 | Fog. |
| | 4 p. m. | − 75 | Warm. |
| Aug. 9 | 8 30 a. m. | − 82 | Overcast. |
| | 7 p. m. | − 81 | Do. |
| Aug. 10 | 8 a. m. | − 84 | Do. |
| | 11 a. m. | − 83 | Clear. |
| | 4 p. m. | − 86 | Do. |
| Aug. 11 | 8 a. m. | − 90 | Do. |
| | 11 30 a. m. | − 86 | Do. |
| | 7 30 p. m. | − 92 | Do. |
| Aug. 12 | 7 30 a. m. | − 96 | Do. |
| | 11 30 a. m. | − 99 | Do. |
| | 4 15 p. m. | − 96 | Do. |
| Aug. 13 | 7 30 a. m. | −101 | Overcast. |
| | 11 30 a. m. | − 98 | Do. |
| | 7 p. m. | −102 | Sun in afternoon. |
| Aug. 14 | 5 45 a. m. | −108 | Overcast. |
| | 8 45 a. m. | −105 | Clearing. |
| Aug. 15 | 11 a. m. | −110 | Overcast. |
| Aug. 16 | 7 30 a. m. | −118 | Do. |
| | 4 p. m. | −117 | Do. |
| Aug. 17 | 7 30 a. m. | −120 | Do. |
| | 11 30 a. m. | −120 | Clear at $9^h30^m$. |
| | 4 30 p. m. | −123 | Clear. |
| Aug. 18 | 7 30 a. m. | −126 | Do. |
| | 11 a. m. | −124 | Do. |
| | 4 p. m. | −126 | Do. |
| Aug. 19 | 7 a. m. | −133 | Clear and sharp. |
| | 11 45 a. m. | −132 | Clear and warm. |
| | 4 15 p. m. | −134 | Do. |
| Aug. 20 | 7 30 a. m. | −134 | Overcast and cool. |
| | 11 30 a. m. | −134 | Warm and sunny. |
| Aug. 21 | 3 30 p. m. | −144 | Do. |
| Aug. 22 | 8 a. m. | −147 | Do. |
| | 11 30 a. m. | −145 | Do. |
| | 5 p. m. | −147 | Do. |
| Aug. 23 | 8 a. m. | −152 | Misting. |
| | 11 a. m. | −152 | Clearing. |
| | 4 30 p. m. | −153 | Clear. |
| Aug. 24 | 7 30 a. m. | −156 | Do. |
| | 11 30 a. m. | −153 | Do. |
| | 4 p. m. | −153 | Do. |
| Aug. 25 | 7 30 a. m. | −160 | Do. |
| | 11 30 a. m. | −153 | Do. |
| | 4 p. m. | −162 | Do. |

TABLE 1—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 26 | $8^h$ $^m$ a. m. | −164 | Overcast. |
| | 11 30 a. m. | −162 | Beginning to clear. |
| | 7 p. m. | −165 | Overcast. |
| Aug. 27 | 6 a. m. | −168 | Do. |
| | 7 a. m. | −169 | |
| | 8 a. m. | −168 | Clear. |
| | 9 a. m. | −165 | Clouds. |
| | 10 a. m. | −163 | Clear. |
| | 11 a. m. | −162 | |
| | 12 m. | −165 | Clouds. |
| | 2 p. m. | −168 | Overcast. |
| | 3 p. m. | −169 | Do. |
| | 4 p. m. | −169 | Do. |
| | 5 p. m. | −169 | Do. |
| | 8 p. m. | −170 | Clear. |
| | 11 p. m. | −174 | Do. |
| Aug. 28 | 3 a. m. | −171 | Overcast. |
| | 4 a. m. | −171 | Do. |
| | 6 a. m. | −171 | Do. |
| | 8 a. m. | −171 | Clearing. |
| | 9 a. m. | −171 | Clear. |
| | 10 a. m. | −169 | Clouds forming. |
| Aug. 28 | 11 a. m. | −170 | Do. |
| | 2 p. m. | −171 | Clear. |
| | 4 p. m. | −168 | Do. |
| | 7 p. m. | −173 | Clouds. |
| | 9 p. m. | −174 | Do. |
| Aug. 29 | 3 a. m. | −175 | Overcast. |
| | 4 a. m. | −175 | Do. |
| | 6 a. m. | −175 | Do. |
| | 8 a. m. | −175 | Do. |
| Aug. 30 | 9 a. m. | −176 | Fog and dew. |
| | 12 m. | −171 | Clear. |
| | 6 p. m. | −154 | Do. |
| Aug. 31 | 9 a. m. | −157 | Do. |
| | 4 p. m. | −156 | Do. |
| Sept. 1 | 7 a. m. | −159 | Rain clouds. |
| | 12 m. | −153 | Clear. |
| | 7 p. m. | −158 | Do. |
| Sept. 2 | 7 a. m. | −162 | |
| | 11 a. m. | −155 | Clear. |
| Sept. 5 | 11 a. m. | −152 | Do. |
| | 6 30 p. m. | −166 | Do. |
| Sept. 6 | 8 30 a. m. | −167 | Clearing after shower. |
| | 6 p. m. | −168 | Clouds. |
| Sept. 7 | 7 30 a. m. | −168 | Clear after shower. |
| | 11 15 a. m. | −165 | Do. |
| | 4 30 p. m. | −170 | Do. |
| Sept. 8 | 7 30 a. m. | −171 | Do. |
| | 11 30 a. m. | −163 | Clear. |
| | 4 p. m. | −170 | Do. |
| Sept. 9 | 8 a. m. | −173 | Cloudy since early morning. |
| | 11 30 a. m. | −168 | Clear. |
| Sept. 10 | 7 30 a. m. | −173 | Cloudy. |
| Sept. 13 | 8 a. m. | −176 | Clearing. |
| | 6 p. m. | −176 | Clear. |
| Sept. 14 | 7 15 a. m. | −178 | Do. |
| | 11 30 a. m. | −173 | Do. |
| | 4 p. m. | −176 | Do. |

TABLE 1—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Sept. 15 | $7^h 15^m$ a. m. | −178 | Clear. |
| | 3 30 p. m. | −176 | Do. |
| Sept. 16 | 7 30 a. m. | −180 | Clear, some clouds. |
| Sept. 18 | 7 a. m. | −183 | Rain on 17th. Clouds. |
| Sept. 20 | 9 a. m. | −181 | Clear and cool. |
| Sept. 21 | 7 30 a. m. | −185 | Do. |
| | 11 30 a. m. | −176 | Clear. |
| | 4 p. m. | −183 | Clear and cool. |
| Sept. 22 | 7 30 a. m. | −184 | Clear. |
| | 11 30 a. m. | −178 | Do. |
| | 5 30 p. m. | −185 | Cloudy since 5 p. m. |
| Sept. 23 | 8 a. m. | −187 | Cloudy. |
| | 12 m. | −183 | Clear after 9 a. m. |
| | 4 p. m. | −185 | Cloudy. |
| Sept. 24 | 7 15 a. m. | −187 | Overcast. |
| | 11 30 a. m. | −186 | Clearing. |
| | 4 p. m. | −186 | Clouds. |
| Sept. 25 | 8 a. m. | −187 | Clear. |
| | 5 p. m. | −187 | Do. |
| Sept. 26 | 7 15 a. m. | −188 | Do. |
| | 11 45 a. m. | −180 | Do. |
| | 4 p. m. | −185 | Do. |
| Sept. 28 | 7 30 a. m. | −187 | Some clouds. |
| Sept. 29 | 9 45 a. m. | −190 | Clear. |
| Oct. 4 | 9 a. m. | −187 | Do. |
| | 4 p. m. | −187 | Do. |
| Oct. 5 | 7 30 a. m. | −188 | Do. |
| | 2 30 p. m. | −185 | Clouds. |
| Oct. 6 | 7 30 a. m. | −188 | Clear. |
| | 5 p. m. | −185 | |
| Oct. 7 | 7 45 a. m. | −187 | Clear. |
| | 12 m. | −181 | Do. |
| | 3 p. m. | −183 | Do. |
| | 6 30 p. m. | −185 | Do. |
| Oct. 8 | 7 30 a. m. | −187 | Do. |
| | 4 p. m. | −182 | Do. |
| Oct. 9 | 7 30 a. m. | −185 | Cloudy. |
| | 3 30 p. m. | −182 | Do. |
| Oct. 10 | 8 a. m. | −182 | Cloudy. |
| | 12 m. | −182 | Overcast. |
| | 4 p. m. | −183 | Do. |
| Oct. 12 | 8 a. m. | −188 | Cloudy; raining since noon of 11th. |
| | 4 p. m. | −183 | Clouds and sun. |
| Oct. 13 | 8 a. m. | −186 | Clear and cold. |
| | 2 p. m. | −182 | Do. |
| Oct. 14 | 8 a. m. | −186 | Do. |
| Oct. 16 | 9 a. m. | −175 | Cloudy. |
| | 4 p. m. | −173 | Do. |
| Oct. 17 | 8 a. m. | −173 | Do. |
| Oct. 18 | 8 a. m. | −172 | Clear. |
| Oct. 19 | 8 a. m. | −168 | Do. |
| | 9 a. m. | ......... | Reset at −194; small air bubble out. |
| | 4 p. m. | −150 | Clear. |
| Oct. 20 | 7 30 a. m. | −143 | Do. |
| | 2 p. m. | −145 | Do. |
| Oct. 21 | 8 a. m. | −126 | Do. |
| Oct. 22 | 4 p. m. | −140 | Clear; reset at −172. |
| Oct. 23 | 7 a. m. | ......... | Down.[1] |

[1] Instrument taken down, cleaned and refitted. The part of the root enclosed in the sheathing tube was dead, both as to cortex and cambium. A slice was taken from the end.

TABLE 1—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Oct. 23 | 9h m a. m. | −160 | Reset at this point after re-fitting. |
| | 11 a. m. | −156 | Clear and warm. |
| Oct. 24 | 7 a. m. | −157 | Clear. |
| | 12 m. | −155 | Do. |
| | 7 p. m. | −156 | Do. |
| Oct. 25 | 8 a. m. | −157 | Do. |
| Oct. 26 | 7 30 a. m. | −122 | Do. |
| Oct. 27 | 8 a. m. | − 90 | Overcast. |
| | 4 p. m. | − 85 | Clear. |
| Oct. 28 | 7 30 a. m. | − 87 | Overcast. |
| | 4 p. m. | − 88 | Do. |
| Oct. 29 | 2 p. m. | − 90 | Clear. |
| Oct. 30 | 7 30 a. m. | − 93 | Overcast. |
| Oct. 31 | 8 a. m. | − 96 | Do. |
| Nov. 1 | 10 30 a. m. | − 96 | Do. |
| Nov. 2 | 8 a. m. | − 98 | Showers. |
| Nov. 3 | 9 a. m. | −100 | Clearing. |
| Nov. 4 | 8 a. m. | −102 | Do. |
| | 4 p. m. | −103 | Clear. |
| Nov. 5 | 8 a. m. | −105 | Do. |
| | 4 p. m. | −103 | Do. |
| Nov. 6 | 8 a. m. | −105 | Do. |
| | 3 p. m. | −105 | Do. |
| Nov. 7 | 8 a. m. | −107 | Do. |
| Nov. 8 | 10 a. m. | −108 | Do. |
| Nov. 9 | 8 a. m. | −110 | Do. |
| | 3 p. m. | −109 | Cloudy. |
| Nov. 10 | 4 p. m. | −112 | Do. |
| Nov. 11 | 7 30 a. m. | −112 | Raining. |
| | 4 p. m. | −112 | Do. |
| Nov. 12 | 8 a. m. | −114 | Cloudy. |
| | 4 p. m. | −121 | Raining. |
| Nov. 13 | 7 30 a. m. | −115 | Clear. |
| Nov. 14 | 7 30 a. m. | −116 | Do. |
| | 4 p. m. | −116 | Do. |
| Nov. 15 | 8 a. m. | −116 | Clear. |
| | 1 30 p. m. | −120 | Do. |
| | 4 p. m. | −118 | Cloudy. |
| Nov. 16 | 8 a. m. | −120 | Drizzle. |
| Nov. 17 | 7 30 a. m. | −122 | Clear. |
| Nov. 18 | 7 30 a. m. | −123 | Do. |
| | 11 30 a. m. | −122 | Do. |
| | 2 p. m. | −122 | Do. |
| | 7 p. m. | −124 | Do. |
| Nov. 19 | 7 30 a. m. | −124 | Do. |
| Nov. 20 | 8 a. m. | −125 | Do. |
| | 11 30 a. m. | −125 | Do. |
| | 2 p. m. | −125 | Do. |
| | 4 30 p. m. | −126 | Do. |
| Nov. 21 | 8 a. m. | −129 | Overcast. |
| | 12 m. | −127 | Slightly overcast. |
| | 4 p. m. | −128 | Overcast. |
| Nov. 22 | 8 a. m. | −132 | Clear. |
| Nov. 23 | 7 30 a. m. | −132 | Overcast. |
| Nov. 24 | 7 30 a. m. | −137 | Do. |
| | 2 p. m. | −136 | Clear. |
| Nov. 25 | 7 a. m. | −139 | Do. |
| | 2 p. m. | −138 | Hazy. |
| Nov. 26 | 12 m. | −139 | Do. |
| Nov. 27 | 8 a. m. | −142 | Clear. |
| Nov. 28 | 8 a. m. | −145 | Do. |

The root of a pine tree (*Pinus radiata*, No. XII), 14 meters in height and 25 cm. in diameter at the base, was exposed for a length of 2 meters, beginning at a distance of 2 meters from the base of the tree. The root was cut at a distance of 2.5 meters from the base of the tree where it had a diameter of about 12 mm. A manometer was attached

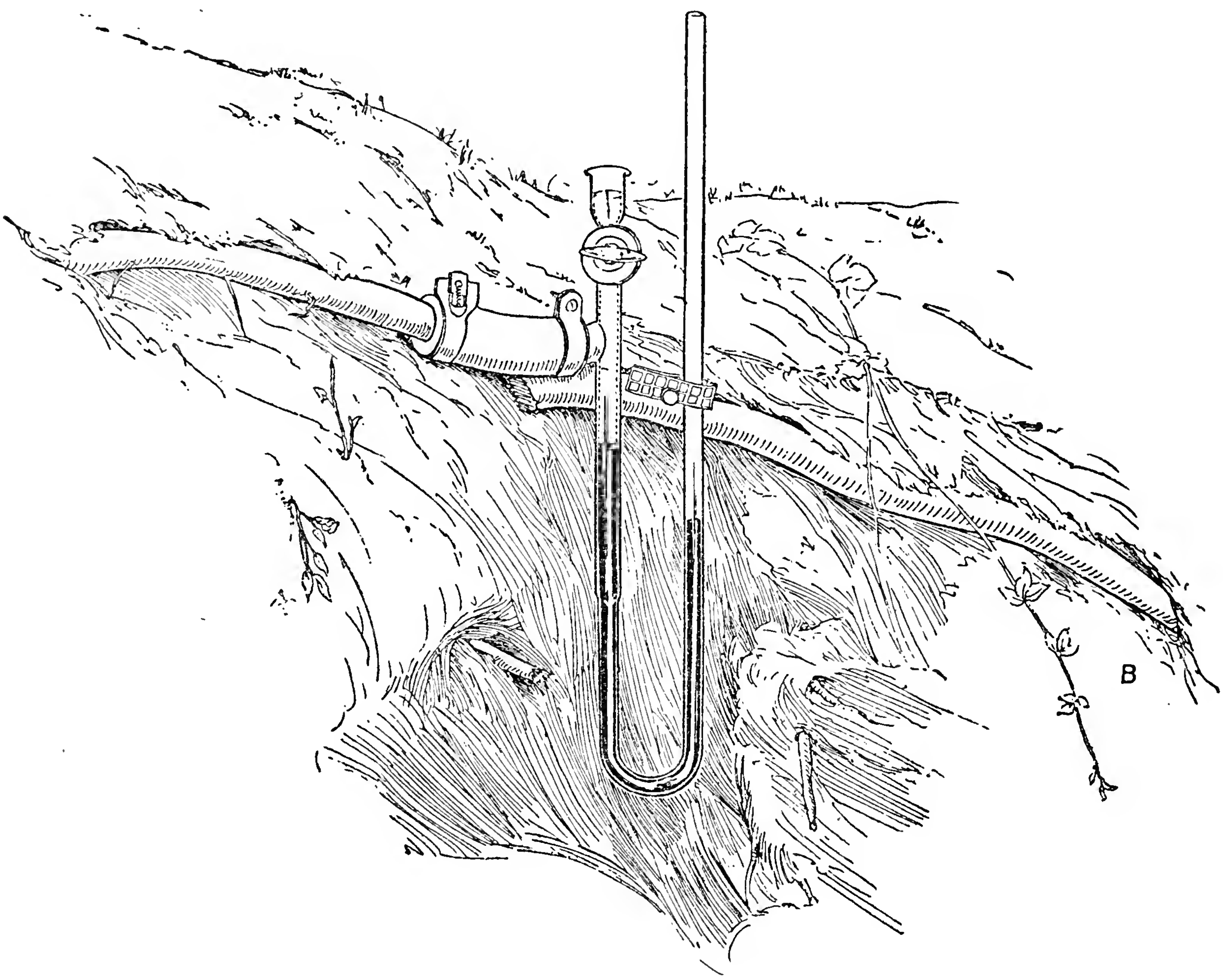



Fig. 5.—Terminal end of root of Monterey pine No. XII with U manometer with open end, showing suction equivalent to about 100 mm. Hg. Portion of separated root was removed and similar instrument attached to stump (See p. 15). B, point at which a second manometer was attached later.

to the terminus of the root as shown in figure 5. A length of 50 cm. was cut from the separated part or stump and a similar manometer attached at B. The leading tubes of both manometers were filled with water and both fittings were completed within 15 minutes after the root was cut. The following records were made, the figures showing − suction or + pressure in mm. of Hg. (Table 2).

TABLE 2.

| Date. | Time. | Terminal. | Stump. | Date. | Time. | Terminal. | Stump. |
|---|---|---|---|---|---|---|---|
| 1925 | | | *mm.* | 1925 | | | *mm.* |
| July 17 | $3^h00^m$ p. m. | Fittings | | Aug. 11 | $8^h$ $^m$ a. m. | − 89 | + 0 |
| | | made. | | | 11 30 a. m. | − 82 | − 0 |
| | 3 15 p. m. | + 5 | + 5 | | 7 p. m. | −102 | − 0 |
| | 4 p. m. | + 30 | + 8 | Aug. 12 | 7 30 a. m. | −110 | − 3 |
| July 18 | 7 a. m. | Air re- | +30 | | 11 30 a. m.[1] | −105 | − 0 |
| | | leased. | | | 4 15 p. m. | −111 | − 0 |
| | 11 30 a. m. | Set to 0 | +35 | Aug. 13 | 7 30 a. m. | −100 | − 2 |
| | 3 p. m. | − 9 | +30 | | 11 30 a. m. | − 93 | − 2 |
| | 4 p. m. | − 10 | +25 | | 7 p. m. | − 86 | − 3 |
| July 19 | 7 40 a. m. | − 27 | +24 | Aug. 14 | 5 45 a. m. | − 80 | − 5 |
| | 10 a. m. | − 30 | − 1 | | 8 45 a. m. | − 68 | − 4 |
| | 5 p. m. | − 41 | − 5 | Aug. 15 | 11 a. m. | − 45 | − 4 |
| July 20 | 7 a. m. | − 54 | − 8 | Aug. 16 | 7 30 a. m. | − 43 | − 6 |
| | 11 30 a. m. | − 54 | − 6 | | 4 p. m. | − 36 | − 5 |
| | 3 30 p. m. | − 60 | − 6 | Aug. 17 | 7 30 a. m. | − 37 | − 8 |
| July 21 | 7 a. m. | − 72 | −10 | | 11 30 a. m. | − 30 | − 7 |
| | 4 p. m. | − 81 | −14 | | 4 p. m. | − 27 | − 9 |
| July 22 | 7 a. m. | − 93 | −18 | Aug. 18 | 7 30 a. m. | − 32 | − 9 |
| | 11 a. m. | − 96 | −24 | | 11 a. m. | − 26 | − 8 |
| | 4 30 p. m. | − 98 | −18 | | 4 p. m. | − 30 | − 9 |
| July 23 | 8 a. m. | −108 | −18 | Aug. 21 | 3 30 p. m. | − 9 | − 9 |
| | 11 45 a. m. | −113 | −20 | Aug. 22 | 8 a. m.[2] | − 15 | −10 |
| | 4 p. m. | −115 | −20 | | 11 30 a. m.[3] | − 8 | |
| July 24 | 7 30 a. m. | −126 | −24 | | 5 p. m. | − 4 | |
| | 4 p. m. | −132 | −24 | Aug. 23 | 8 a. m. | − 8 | |
| | 8 p. m. | −132 | −24 | | 11 a. m. | − 13 | |
| July 25 | 7 30 a. m. | − 69 | −27 | | 4 30 p. m. | − 18 | |
| | 9 a. m. | − 73 | −24 | Aug. 24 | 7 30 a. m. | − 27 | |
| | 12 m. | − 66 | −24 | | 11 a. m. | − 24 | |
| | 3 p. m. | − 66 | −27 | | 4 p. m. | − 31 | |
| July 26 | 7 30 a. m. | − 72 | −30 | Aug. 25 | 7 30 a. m. | − 44 | |
| | 10 a. m. | − 78 | −28 | | 11 30 a. m. | − 39 | |
| | 3 p. m. | − 83 | −27 | | 4 p. m. | − 45 | |
| July 27 | 7 30 a. m. | − 96 | −30 | Aug. 26 | 8 a. m. | − 54 | |
| | 11 a. m. | − 96 | −29 | | 11 30 a. m. | − 54 | |
| | 2 30 p. m. | − 98 | −30 | | 7 15 p. m. | − 62 | |
| July 28 | 7 a. m. | −110 | −30 | Aug. 27 | 6 a. m. | − 68 | |
| | 11 a. m. | −108 | −32 | | 7 a. m. | − 70 | |
| | 2 p. m. | −107 | −36 | | 8 a. m. | − 68 | |
| July 29 | 7 40 a. m. | −108 | −33 | | 9 a. m. | − 66 | |
| July 30 | 8 a. m. | − 60 | −28 | | 10 a. m. | − 65 | |
| | 4 p. m. | − 57 | −33 | | 11 a. m. | − 65 | |
| July 31 | 7 30 a. m. | − 56 | −35 | | 12 m. | − 65 | |
| | 11 30 a. m. | − 54 | −33 | | 2 p. m. | − 68 | |
| Aug. 2 | 3 45 p. m. | − 54 | −37 | | 3 p. m. | − 69 | |
| Aug. 3 | 7 30 a. m. | − 54 | −37 | | 4 p. m. | − 69 | |
| | 11 30 a. m. | − 48 | −36 | | 5 p. m. | − 72 | |
| | 3 40 p. m. | − 50 | −38 | | 8 p. m. | − 76 | |
| Aug. 4 | 8 a. m. | − 51 | −38 | | 11 p. m. | − 79 | |
| | 2 30 p. m. | − 45 | −39 | Aug. 28 | 3 a. m. | − 80 | |
| Aug. 5 | 9 a. m. | − 51 | −41 | | 4 a. m. | − 80 | |
| Aug. 6 | 2 30 p. m. | − 15 | − 0 | | 6 a. m. | − 80 | |
| Aug. 7 | 9 a. m. | − 39 | + 3 | | 8 a. m. | − 81 | |
| | 4 p. m. | − 36 | + 5 | | 9 a. m. | − 80 | |
| Aug. 8 | 8 a. m. | − 50 | + 2 | | 10 a. m. | − 79 | |
| | 4 p. m. | − 54 | + 3 | | 11 a. m. | − 79 | |
| Aug. 9 | 8 30 a. m. | − 66 | + 2 | | 2 p. m. | − 81 | |
| | 10 30 a. m. | − 65 | + 1 | | 4 p. m. | − 81 | |
| | 7 p. m. | − 72 | + 0 | | 7 p. m. | − 86 | |
| Aug. 10 | 8 a. m. | − 81 | 0 | | 9 p. m. | − 87 | |
| | 11 a. m. | − 78 | + 2 | Aug. 29 | 3 a. m. | − 90 | |
| | 4 p. m. | − 86 | + 1 | | 4 a. m. | − 90 | |

[1] Soil about entire root irrigated for 30 hours. [2] Closed. [3] Air released; set to 0.

TABLE 2—*Continued.*

| Date. | Time. | Terminal. | Remarks. | Date. | Time. | Terminal. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1925 | | | | 1925 | | | |
| Aug. 29 | 6h m a. m. | − 91 | | Oct. 7 | 7h45m a. m. | − 71 | |
| | 8 a. m. | − 92 | | | 12 m. | − 71 | |
| Aug. 30 | 9 a. m. | − 45 | | | 3 15 p. m. | − 73 | |
| | 12 m. | − 43 | | | 6 30 p. m. | − 60 | |
| | 6 p. m. | − 51 | | Oct. 8 | 7 30 a. m. | − 78 | |
| Aug. 31 | 9 a. m. | − 62 | | | 4 p. m. | − 84 | |
| | 4 p. m. | − 65 | | Oct. 9 | 7 30 a. m. | − 90 | |
| Sept. 1 | 7 a. m. | − 75 | | | 3 30 p. m. | − 92 | |
| | 8 a. m. | − 72 | | Oct. 10 | 8 a. m. | − 98 | |
| | 7 p. m. | − 84 | | | 12 m. | − 98 | |
| Sept. 2 | 7 a. m. | − 88 | | | 4 p. m. | −101 | |
| | 11 a. m. | − 82 | | Oct. 11 | 8 a. m. | −105 | |
| Sept. 5 | 11 a. m. | − 87 | | Oct. 12 | 8 a. m. | −115 | |
| | 6 30 p. m. | − 97 | | | 4 p. m. | −116 | |
| Sept. 6 | 8 30 a. m. | − 75 | | Oct. 13 | 8 a. m. | −134 | |
| | 6 p. m. | − 50 | | | 2 p. m. | −122 | |
| Sept. 7 | 7 30 a. m. | − 67 | | Oct. 14 | 8 a. m. | −126 | |
| | 11 15 a. m. | − 58 | | Oct. 16 | 9 a. m. | −133 | |
| | 4 30 p. m. | − 68 | | | 4 p. m. | −134 | |
| Sept. 8 | 7 30 a. m. | − 80 | | Oct. 17 | 9 a. m. | −140 | |
| | 11 30 a. m. | − 72 | | Oct. 18 | 8 a. m. | −148 | |
| | 4 p. m. | − 79 | | Oct. 19 | 9 a. m. | −156 | Clear. |
| Sept. 9 | 8 a. m. | − 83 | | | 4 p. m. | −155 | Do. |
| | 11 30 a. m. | − 69 | | Oct. 20 | 7 30 a. m. | −162 | Do. |
| Sept. 10 | 7 30 a. m. | − 57 | | | 2 p. m. | −158 | Do. |
| Sept. 13 | 8 a. m. | − 27 | | Oct. 21 | 8 a. m. | −156 | Do. |
| | 6 p. m. | − 30 | | Oct. 22 | 4 p. m. | −159 | Do. |
| Sept. 14 | 7 15 a. m. | − 35 | | Oct. 23 | 8 a. m. | − 48 | Do. |
| | 11 30 a. m. | − 17 | | | 11 a. m. | − 44 | Do. |
| | 3 p. m.[1] | − 23 | | Oct. 24 | 7 a. m. | − 66 | Do. |
| Sept. 15 | 7 15 a. m. | − 56 | | | 12 m. | − 62 | Do. |
| | 3 30 p. m. | − 56 | | | 7 p. m. | − 72 | Do. |
| Sept. 16 | 7 30 a. m. | − 68 | | Oct. 25 | 8 a. m. | − 65 | Do. |
| Sept. 18 | 7 a. m. | −108 | | Oct. 26 | 7 30 a. m. | − 84 | Do. |
| Sept. 20 | 9 a. m. | − 98 | | Oct. 27 | 8 a. m. | − 94 | Overcast. |
| Sept. 21 | 7 30 a. m. | −140 | | | 4 p. m. | − 93 | Clear. |
| | 11 a. m. | −138 | | Oct. 28 | 7 30 a. m. | − 99 | Overcast. |
| | 4 p. m. | −139 | | | 4 p. m. | − 98 | Do. |
| Sept. 22 | 7 30 a. m. | − 73 | | Oct. 29 | 2 p. m. | −102 | Clear. |
| | 11 30 a. m. | − 62 | | Oct. 30 | 7 30 a. m. | −108 | Overcast. |
| | 5 30 p. m. | − 72 | | Oct. 31 | 8 a. m. | −114 | Do. |
| Sept. 23 | 8 a. m. | − 81 | | Nov. 1 | 10 30 a. m. | −117 | Do. |
| | 12 m. | − 80 | | Nov. 2 | 8 a. m. | −125 | Showers. |
| | 4 p. m. | − 84 | | Nov. 3 | 9 a. m. | −132 | Clearing. |
| Sept. 24 | 7 15 a. m. | − 92 | | Nov. 4 | 8 a. m. | −124 | Do. |
| | 11 30 a. m. | − 90 | | | 4 p. m. | −134 | Clear. |
| | 4 p. m. | − 87 | | Nov. 5 | 8 a. m. | −144 | Do. |
| Sept. 25 | 8 a. m. | − 99 | | | 4 p. m. | −140 | |
| | 5 p. m. | −102 | | Nov. 6 | 7 30 a. m. | −150 | |
| Sept. 26 | 7 15 a. m. | −111 | | | 3 p. m. | −143 | |
| | 11 45 a. m. | −118 | | Nov. 7 | 8 a. m. | −162 | Clear. |
| | 4 p. m. | −110 | | Nov. 8 | 10 a. m. | −149 | Do. |
| Sept. 28 | 7 30 a. m. | − 42 | | Nov. 9 | 8 a. m. | −137 | Do. |
| Sept. 29 | 9 45 a. m. | − 63 | | | 3 p. m. | −151 | Cloudy. |
| Sept. 30 | 4 p. m. | − 68 | | Nov. 10 | 4 p. m. | −146 | Do. |
| Oct. 4 | 9 a. m.[2] | − 42 | | Nov. 11 | 7 30 p. m. | −150 | Raining. |
| | 4 p. m. | − 44 | | | 4 p. m. | −139 | Do. |
| Oct. 5 | 7 30 a. m. | − 50 | | Nov. 12 | 8 a. m. | −114 | Cloudy. |
| | 2 30 p. m. | − 54 | | | 4 p. m. | −111 | Raining. |
| Oct. 6 | 7 30 a. m. | − 61 | | Nov. 13 | 7 30 a. m. | −108 | Clear. |
| | 5 p. m. | − 66 | | Nov. 14 | 7 30 a. m. | −108 | Do. |

[1] Air released; set at −40. [2] Air released; set at 0.

TABLE 2—*Continued.*

| Date. | Time. | Terminal. | Remarks. | Date. | Time. | Terminal. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1925 | | | | 1925 | | | |
| Nov. 14 | $4^{\mathrm{h}}\ {}^{\mathrm{m}}$ p. m. | −101 | Clear. | Nov. 20 | $4^{\mathrm{h}}30^{\mathrm{m}}$ p. m. | − 99 | Clear. |
| Nov. 15 | 8 a. m. | − 87 | Do. | Nov. 21 | 8 a. m. | −111 | Overcast. |
| | 1 30 p. m. | − 84 | Do. | | 12 m. | − 98 | Slightly |
| | 4 p. m. | − 86 | Cloudy. | | | | overcast. |
| Nov. 16 | 8 a. m. | − 86 | Drizzle. | | 4 p. m. | −100 | Overcast. |
| Nov. 17 | 7 30 a. m. | − 97 | Clear. | Nov. 22 | 8 a. m. | −112 | Clear. |
| Nov. 18 | 7 30 a. m. | −101 | Do. | Nov. 23 | 7 30 a. m. | −111 | Overcast. |
| | 11 30 a. m. | − 94 | Do. | Nov. 24 | 7 30 a. m. | −108 | Do. |
| | 2 p. m. | − 93 | Do. | | 2 p. m. | −107 | Clear. |
| | 7 p. m. | − 98 | Do. | Nov. 25 | 7 a. m. | −115 | Do. |
| Nov. 19 | 7 30 a. m. | −102 | Do. | | 2 p. m. | −104 | Hazy. |
| Nov. 20 | 8 a. m. | −108 | Do. | Nov. 26 | 12 m. | −104 | Do. |
| | 11 30 a. m. | − 97 | Do. | Nov. 27 | 8 a. m. | −120 | Clear. |
| | 2 p. m. | − 96 | Do. | Nov. 28 | 8 a. m. | −110 | Do. |

## Factors in Suction and Pressure in Roots of Pinus.

The attachment of manometers to the distal ends of living pine roots in functional connection with trees would entail a preliminary exudation of resin and the collapse of living cells with an addition of their contents to the liquid bathing the surfaces. Some elongated conduits in the central part of the stem might contain gases which would be displaced to some extent by capillary injection. Variations in the volume and pressure of the gaseous contents of the central cylinder of the trunk communicating with this tract would give the implied effects. It might be expected, however, that the determining feature would be the pull from the leaves extending downward in the water column to the liquid in the instrument.

The preliminary action of the smaller root (Table 1), the woody cylinder of which was only 5 mm. in diameter, showed no positive pressures, a matter possibly due to size relations to the instrument or to defective fittings. The larger root exhibited such positive action in the distal end and on the stump of the separated root. Exudation from the separated root was seen 25 days later. The irregularities of the record of the smaller root suggest defective fittings, and it was not until a fortnight after the beginning of the test that reliance could be placed on the fittings. After this it may be seen that on clear days suction was lessened at mid-day in a manner suggestive of the expansion of included gases, and that but little variation was exhibited on days which were overcast and equable. The variations, however, were very slight, as would be the case with the small amount of gas which could be included. The amount of suction which reached a maximum of −188 mm. Hg. = 0.25 atm., and ran near this for some time, would be determined by the tension in the water-column. The greatest daily variation was only −8 mm. Hg., and this was late in September at a time of greatest daily range of temperature.

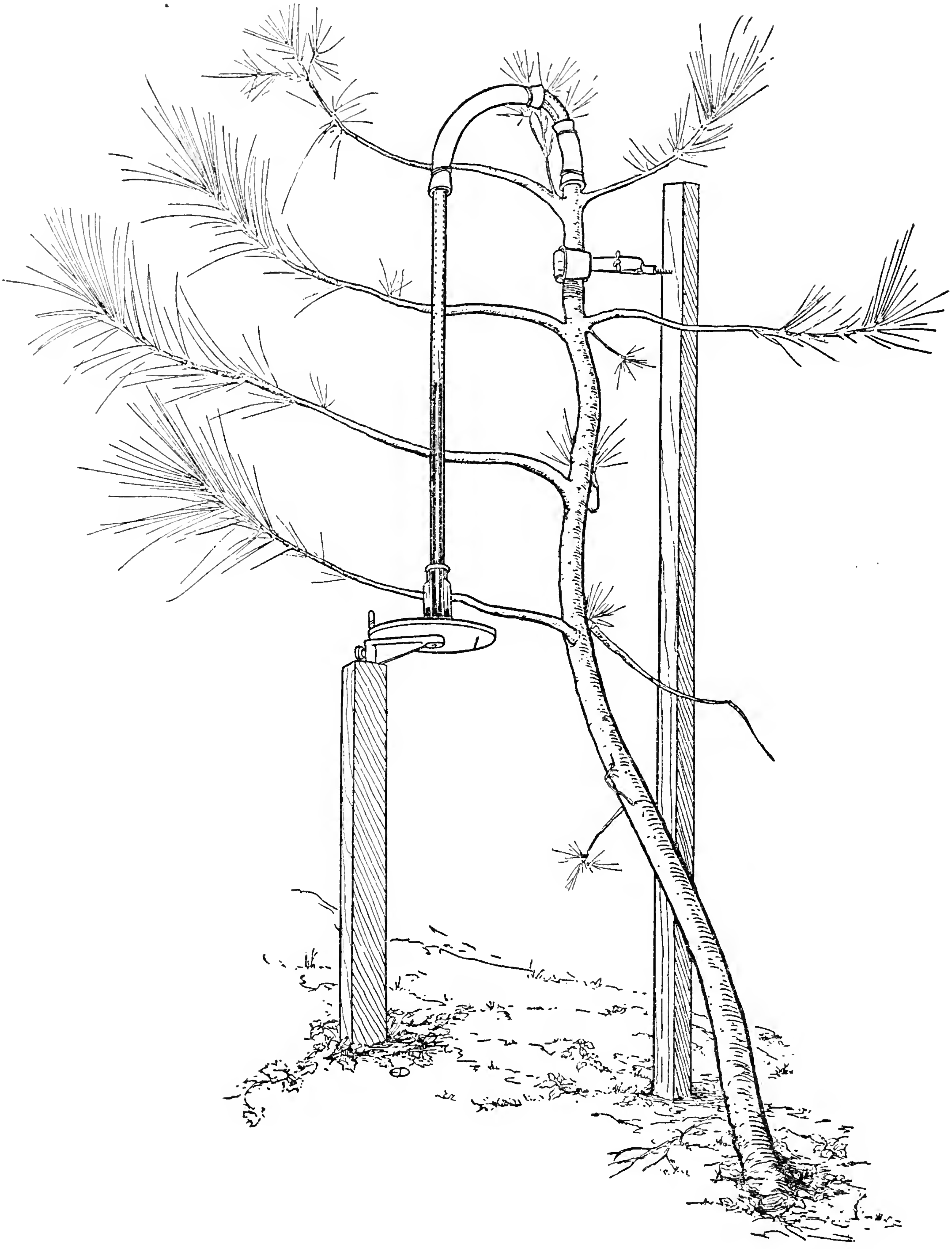


Fig. 6.—Small tree of Monterey pine No. XIII, which was topped in April 1925 and a manometer attached and kept in adjustment for 7 months. Only a small proportion of leaves was removed, and the leafy branches maintained a normal condition throughout the observations.

Following the initial period in which exudation appeared and suction was lessened in the larger root, the daily increase in tension in the water-column affected the suction, and this continued for about 10 days. Afterward the familiar cycle of change was apparent. This may be illustrated by the records of morning, noon and evening of −37, −30 and −27 on Aug. 17; and of −80, −72 and −79 on September 8. The greatest daily variation was equivalent to 11 mm. Hg., and the maximum suction was −162 mm. Hg. = 0.21 atmospheres in November. It was noted here as in the trunk that, when the instrument was opened and reset to 0, suction reached some magnitude at once, then slowly increased to a maximum which might not be reached for many days.

The tests of the separated part of the root were continued for only 36 days. Pressures of +35 mm. Hg. were exhibited on the first few days, then suction reaching a maximum of −41 mm. Hg. 19 days after the test was begun, to be followed by positive pressures of +3 mm. Hg., and low suction not surpassing 10 mm. Hg., which is to be contrasted with the action of a separated root of Juglans discussed in a later section of this paper.

It was found that an ample irrigation of the soil about this root had no perceptible effect on suction in either portion of the root.

## Variations in Suction at Top of Small Tree.

The removal of a branch or the terminal of a stem cuts across the entire hydrostatic system of the tree, various anatomical elements exposed being different from those of excised roots. The central cylinder containing gases is tapped more freely than in an excised root. This was tested first in a small tree about 2 meters in height, which had grown in a shaded place, making thin annual layers of wood.

The above tree (*Pinus radiata*, No. XIII) was topped at a height of 110 cm. from the base and a manometer attached as in figure 6. This instrument was replaced later by one which made it possible to release air drawn from the stem. As shown in figure 6, six small branches furnished a fairly adequate means of transpiration. Records were made of suction in terms of mm. of Hg. (Table 3).

TABLE 3.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Apr. 15 | $3^h15^m$ a. m. | ......... | Attached within few minutes after decapitation. |
| | 3 30 p. m. | − 16 | |
| | 3 40 p. m. | − 25 | |
| | 4 10 p. m. | − 50 | |
| | 4 30 p. m. | − 66 | |
| Apr. 16 | 8 a. m. | −172 | |
| | 10 a. m. | −180 | |
| Apr. 17 | 8 a. m. | −166 | Rubber tube was disconnected from stump, small section taken off, and reset with Hg. at 0. |
| | 10 30 a. m. | −180 | |
| | 2 p. m. | −154 | Absorption pressure now fell and 20 days later was at 0. |
| May 14 | 8 a. m. | − 0 | Instrument disconnected, surface pared, and instrument reset at 0. |
| | 2 p. m. | − 10 | |
| May 15 | 8 a. m. | − 4 | |
| May 16 | 8 a. m. | − 2 | |
| | 3 a. m. | − 2 | Another section 3 cm. long cut from end of stem, surface being 4 cm. from uppermost pair of branches. |
| May 17 | 8 a. m. | −100 | |
| | 3 30 p. m. | −126 | |
| May 18 | 8 a. m. | −120 | |
| May 19 | 2 p. m. | −118 | Rain all night and continuing day. |
| May 20 | 8 30 a. m. | −120 | |
| | 3 30 p. m. | −120 | |
| May 22 | 8 a. m. | −104 | |
| May 24 | 10 a. m. | − 96 | |
| | 4 p. m. | − 60 | |
| May 26 | 8 a. m. | − 84 | |
| | 11 30 a. m. | − 86 | |
| May 27 | 9 a. m. | −114 | |
| | 3 p. m. | −116 | |
| May 28 | 8 a. m. | −126 | |
| | 11 30 a. m. | −120 | |
| May 29 | 7 30 a. m. | −128 | |
| | 4 p. m. | −128 | Air bubble released; set to 0. |
| May 30 | 8 a. m. | − 34 | |
| | 2 p. m. | − 50 | |
| May 31 | 8 30 a. m. | − 82 | Raining. |
| | 11 a. m. | − 80 | |
| | 5 30 p. m. | −104 | |
| June 1 | 7 a. m. | −104 | Raining. |
| June 2 | 8 a. m. | −110 | |
| | 12 m. | −106 | Cloudy followed by clearing; rain in night. |
| June 3 | 7 a. m. | −110 | |
| | 4 p. m. | −116 | Clear and windy. |
| June 4 | 8 a. m. | −114 | Reset to 0. |
| | 11 30 a. m. | − 14 | |
| June 5 | 7 a. m. | − 66 | Raining. |
| | 4 p. m. | − 84 | |
| June 6 | 7 a. m. | −110 | Cloudy. |
| | 4 p. m. | −120 | Clear. |
| June 7 | 8 a. m. | −140 | Clear. |
| June 8 | 7 a. m. | −136 | Overcast. |
| | 4 p. m. | −134 | Clear; reset. |
| June 9 | 7 a. m. | − 54 | |
| | 3 p. m. | − 90 | Cloudy. |
| June 13 | 7 a. m. | − 90 | Do. |
| | 9 a. m. | − 90 | Cloudy; reset to 0. |
| | 4 p. m. | − 20 | |
| June 14 | 8 a. m. | − 44 | Cloudy. |
| | 9 a. m. | − 36 | |
| June 15 | 8 a. m. | − 46 | |
| | 2 p. m. | − 50 | Clear. |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| June 16 | $8^h$ $^m$ a. m. | − 66 | Cloudy. |
| | 4 p. m. | − 60 | Do. |
| June 17 | 9 a. m. | − 80 | Do. |
| | 12 m. | − 80 | Do. |
| | 4 p. m. | − 84 | Do. |
| June 18 | 3 p. m. | −110 | Cloudy. |
| June 19 | 7 a. m. | −118 | Clear. |
| | 11 30 a. m. | − 76 | Clouding. |
| | 2 30 p. m. | − 90 | Clearing. |
| June 20 | 8 a. m. | −106 | Fog. |
| | 12 m. | −110 | Do. |
| | 4 p. m. | −114 | Do. |
| June 21 | 8 a. m. | − 84 | Fog; reset to 0. |
| | 12 m. | − 10 | Fog. |
| June 22 | 7 a. m. | − 44 | Clearing. |
| | 10 a. m. | − 40 | |
| | 4 p. m. | − 54 | Clear. |
| June 23 | 8 a. m. | − 60 | Do. |
| | 10 30 a. m. | − 76 | Do. |
| June 24 | 7 a. m. | −100 | Do. |
| | 11 a. m. | −106 | |
| | 2 p. m. | − 90 | Clear. |
| June 25 | 7 a. m. | − 88 | Do. |
| | 12 m. | −110 | Do. |
| | 4 p. m. | −100 | Do. |
| June 26 | 7 a. m. | −132 | |
| | 4 30 p. m. | − 96 | |
| June 27 | 8 a. m. | − 96 | Cloudy. |
| | 3 p. m. | −100 | Do. |
| June 28 | 8 a. m. | −100 | |
| | 4 p. m. | −100 | Cool. |
| June 29 | 9 a. m. | −104 | Do. |
| | 4 p. m. | −106 | Do. |
| June 30 | 7 a. m. | −104 | Air released; set to 0. |
| June 30 | 2 p. m. | − 3 | Clear. |
| July 1 | 7 a. m. | − 6 | Do. |
| | 8 p. m. | − 6 | Fog. |
| July 2 | 7 a. m. | − 24 | Do. |
| | 7 p. m. | − 26 | Do. |
| July 3 | 7 a. m. | − 28 | Reset to 0. |
| | 2 30 p. m. | − 0 | |
| | 5 p. m. | − 0 | Fog. |
| July 4 | 9 a. m. | − 9 | Do. |
| | 11 a. m. | − 0 | Sunny. |
| | 3 30 p. m. | − 12 | Sunny. |
| July 5 | 8 30 a. m. | − 18 | Overcast. |
| | 10 30 a. m. | − 8 | Clear. |
| | 4 30 p. m. | − 21 | Do. |
| July 6 | 7 a. m. | − 20 | Do. |
| | 11 a. m. | − 10 | Do. |
| | 6 30 p. m. | − 10 | Do. |
| July 7 | 7 a. m. | − 18 | Overcast. |
| | 9 a. m. | − 18 | Do. |
| | 2 p. m. | − 10 | Sunny. |
| | 4 p. m. | − 15 | Do. |
| July 8 | 7 30 a. m. | − 15 | Air released; reset to 0. |
| | 2 p. m. | − 2 | |
| | 4 p. m. | − 4 | |
| July 9 | 7 30 a. m. | − 6 | Fog and drizzle. |
| | 10 30 a. m. | − 6 | Do. |
| | 4 p. m. | − 4 | Overcast. |
| July 11 | 7 30 a. m. | − 6 | Clear. |
| | 11 a. m. | − 3 | Do. |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 11 | $2^h30^m$ p. m. | − 3 | Clear. |
| | 4 30 p. m. | − 8 | Do. |
| July 12 | 8 a. m. | − 7 | Do. |
| | 10 30 a. m. | − 3 | Do. |
| July 13 | 7 30 a. m. | − 10 | Do. |
| | 9 30 a. m. | − 7 | Do. |
| | 12 m. | − 6 | Do. |
| | 3 30 p. m. | − 10 | Do. |
| July 14 | 7 30 a. m. | − 11 | Do. |
| | 11 15 a. m. | − 10 | Clouds and sunshine. |
| | 2 15 p. m. | − 12 | Do. |
| July 15 | 7 30 a. m. | − 14 | Foggy. |
| | 9 30 a. m. | − 12 | Clear. |
| | 1 30 p. m. | − 14 | |
| July 16 | 7 a. m. | − 14 | Clear. |
| | 11 a. m. | − 10 | Do. |
| | 3 30 p. m. | − 14 | Do. |
| July 17 | 7 a. m. | − 14 | Do. |
| | 3 15 p. m. | − 15 | Do. |
| July 18 | 7 a. m. | − 18 | Clouds. |
| | 11 30 a. m. | − 18 | Do. |
| | 4 p. m. | − 18 | Do. |
| July 19 | 7 40 a. m. | − 20 | Do. |
| | 10 a. m. | − 23 | Do. |
| | 5 p. m. | − 20 | Cloudy. |
| July 20 | 7 a. m. | − 20 | Cloudy; taken down, a few mm. sliced from end and reset at 0. |
| | 11 30 a. m. | − 2 | Clouds. |
| | 3 30 p. m. | − 5 | Clear. |
| July 21 | 7 a. m. | − 14 | Overcast. |
| | 11 a. m. | − 14 | Do. |
| | 4 p. m. | − 15 | Clouds. |
| July 22 | 7 a. m. | − 21 | Drizzling. |
| | 11 a. m. | − 24 | Do. |
| | 4 30 p. m. | − 23 | Overcast. |
| July 23 | 8 a. m. | − 27 | Warmer. |
| | 11 45 a. m. | − 27 | Clear. |
| | 4 p. m. | − 30 | Do. |
| July 24 | 7 30 a. m. | − 36 | Cloudy. |
| | 4 p. m. | − 38 | Clouds and sunshine. |
| | 8 p. m. | − 38 | Do. |
| July 25 | 7 30 a. m. | − 44 | Overcast. |
| | 9 a. m. | − 43 | Clear. |
| | 12 m. | − 42 | Do. |
| | 3 p. m. | − 43 | Clouds. |
| July 26 | 7 30 a. m. | − 51 | Fog. |
| | 10 a. m. | − 50 | Overcast. |
| | 3 p. m. | − 51 | Do. |
| July 27 | 7 30 a. m. | − 56 | Do. |
| | 11 30 a. m. | − 56 | Do. |
| | 3 30 p. m. | − 57 | Do. |
| July 28 | 7 a. m. | − 60 | Do. |
| | 11 a. m. | − 62 | Do. |
| | 2 p. m. | − 62 | Sunny. |
| July 29 | 7 40 a. m. | − 68 | Overcast. |
| July 30 | 8 a. m. | − 72 | Dripping fog. |
| | 4 p. m. | − 79 | Overcast. |
| July 31 | 7 30 a. m. | − 78 | Do. |
| July 31 | 11 30 a. m. | − 78 | Clearing. |
| Aug. 2 | 3 45 p. m. | − 92 | Clear. |
| Aug. 3 | 7 30 a. m. | − 97 | Overcast. |
| | 11 30 a. m. | − 98 | Clear. |
| | 3 40 a. m. | − 98 | Do. |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 4 | $8^h$ $^m$ a. m. | −104 | Overcast. |
| | 2 30 p. m. | −104 | Sunny. |
| Aug. 5 | 9 a. m. | −110 | Fog. |
| Aug. 6 | 2 30 p. m. | −117 | Sunshine. |
| Aug. 7 | 9 a. m. | −125 | Fog. |
| | 4 p. m. | −138 | Sunny. |
| Aug. 8 | 8 a. m. | −132 | Foggy. |
| | 4 p. m. | −134 | |
| Aug. 9 | 8 30 a. m. | −138 | Overcast. |
| | 7 p. m. | −144 | Do. |
| Aug. 10 | 8 a. m. | −146 | Do. |
| | 11 a. m. | −146 | Clear. |
| | 4 p. m. | −149 | Do. |
| Aug. 11 | 8 a. m. | −153 | Do. |
| | 11 30 a. m. | −145 | Do. |
| | 7 p. m. | −160 | Do. |
| Aug. 12 | 7 30 a. m. | −162 | Do. |
| | 11 30 a. m. | −164 | Do. |
| | 4 15 p. m. | −165 | Do. |
| Aug. 13 | 7 30 a. m. | −170 | Overcast. |
| | 11 30 a. m. | −170 | |
| | 7 p. m. | −174 | Clear in afternoon. |
| Aug. 14 | 5 45 a. m. | −178 | Overcast. |
| | 8 45 a. m. | −176 | Clearing. |
| Aug. 15 | 11 a. m. | −186 | Overcast. |
| Aug. 16 | 7 30 a. m. | −190 | Do. |
| | 4 p. m. | −192 | Do. |
| Aug. 17 | 7 30 a. m. | −198 | Do. |
| | 11 30 a. m. | −189 | Clear at $9^h30^m$ a. m. |
| | 4 p. m. | −204 | |
| Aug. 18 | 7 30 a. m. | −204 | |
| | 11 a. m. | −204 | |
| | 4 p. m. | −206 | |
| Aug. 19 | 7 a. m. | −210 | Clear. |
| | 4 15 p. m. | −210 | |
| Aug. 20 | 7 30 a. m. | −213 | U tube replaced by vertical column and reset at 0. |
| Aug. 21 | 3 30 p. m. | − 16 | |
| Aug. 22 | 8 a. m. | − 20 | Clear. |
| | 11 30 a. m. | − 20 | Do. |
| | 5 p. m. | − 23 | Do. |
| Aug. 23 | 8 a. m. | − 27 | Misting. |
| | 11 a. m. | − 32 | Clearing. |
| | 4 30 p. m. | − 30 | Sunny. |
| Aug. 24 | 7 30 a. m. | − 35 | Do. |
| | 11 30 a. m. | − 33 | Do. |
| | 4 p. m. | − 37 | Do. |
| Aug. 25 | 7 30 a. m. | − 60 | Clear. |
| | 11 30 a. m. | − 42 | Do. |
| | 4 p. m. | − 47 | Do. |
| Aug. 26 | 8 a. m. | − 50 | Overcast. |
| | 11 30 a. m. | − 57 | Beginning to clear. |
| | 7 15 p. m. | − 50 | Overcast. |
| Aug. 27 | 6 a. m. | − 53 | |
| | 7 a. m. | − 55 | |
| | 8 a. m. | − 54 | |
| | 9 a. m. | − 54 | |
| | 10 a. m. | − 55 | |
| | 11 a. m. | − 55 | |
| | 12 m. | − 55 | |
| | 2 p. m. | − 56 | |
| | 3 p. m. | − 55 | |
| | 4 p. m. | − 56 | |
| | 5 p. m. | − 58 | |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 27 | 8h m p. m. | − 60 | |
| | 11 p. m. | − 58 | |
| Aug. 28 | 3 a. m. | − 58 | |
| | 4 a. m. | − 60 | |
| | 6 a. m. | − 60 | |
| | 8 a. m. | − 60 | |
| | 9 a. m. | − 61 | |
| | 10 a. m. | − 62 | |
| | 11 a. m. | − 62 | |
| | 2 p. m. | − 63 | |
| | 4 p. m. | − 63 | |
| | 7 p. m. | − 65 | |
| | 9 p. m. | − 66 | |
| Aug. 29 | 3 a. m. | − 70 | |
| | 4 a. m. | − 74 | |
| | 6 a. m. | − 66 | |
| | 8 a. m. | − 68 | |
| Aug. 30 | 9 a. m. | − 75 | Fog. |
| Aug. 30 | 12 m. | − 70 | Sunny. |
| | 6 p. m. | − 78 | Do. |
| Aug. 31 | 9 a. m. | − 80 | Do. |
| | 4 p. m. | − 82 | Do. |
| Sept. 1 | 7 a. m. | − 86 | Clouds. |
| | 12 m. | − 88 | Sunny. |
| | 7 p. m. | − 94 | Clear. |
| Sept. 2 | 7 a. m. | − 92 | Clearing. |
| | 11 a. m. | − 93 | Clear. |
| Sept. 5 | 11 a. m. | −112 | |
| | 6 30 p. m. | −117 | Clear. |
| Sept. 6 | 8 30 a. m. | −120 | Clearing after shower. |
| | 6 p. m. | −124 | Clouds. |
| Sept. 7 | 7 30 a. m. | −126 | Clearing after shower. |
| | 11 15 a. m. | −128 | Clear. |
| | 4 30 p. m. | −128 | Do. |
| Sept. 8 | 7 30 a. m. | −132 | Do. |
| | 11 30 a. m. | −131 | Do. |
| | 4 p. m. | −135 | Do. |
| Sept. 9 | 8 a. m. | −137 | Cloudy. |
| | 11 30 a. m. | −136 | Clear. |
| Sept. 10 | 7 30 a. m. | −142 | Cloudy. |
| Sept. 13 | 8 a. m. | −151 | Clearing. |
| | 6 p. m. | −156 | Clear. |
| Sept. 14 | 7 15 a. m. | −156 | Do. |
| | 11 30 a. m. | −154 | Do. |
| | 4 p. m. | −155 | Do. |
| Sept. 15 | 7 15 a. m. | −158 | Do. |
| | 3 30 p. m. | −157 | Do. |
| Sept. 16 | 7 30 a. m. | −162 | Some clouds. |
| Sept. 18 | 7 a. m. | −171 | Clouds; rain on 17th. |
| Sept. 20 | 9 a. m. | −173 | Clear. |
| Sept. 21 | 7 30 a. m. | −177 | Do. |
| | 11 30 a. m. | −175 | Do. |
| | 4 p. m. | −176 | Do. |
| Sept. 22 | 7 30 a. m. | −194 | Do. |
| | 11 30 a. m. | −178 | Do. |
| | 5 30 p. m. | −180 | Cloudy. |
| Sept. 23 | 8 a. m. | −182 | Do. |
| | 12 m. | −183 | Do. |
| | 4 p. m. | −181 | Do. |
| Sept. 24 | 7 15 a. m. | −185 | Overcast. |
| | 11 30 a. m. | −184 | Clearing. |
| | 4 p. m. | −183 | Clouds. |
| Sept. 25 | 8 a. m. | −186 | Clear. |
| | 5 p. m. | −186 | Do. |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Sept. 26 | $7^h15^m$ a. m. | −187 | Clear. |
| | 11 45 a. m. | −186 | Do. |
| Sept. 28 | 7 30 a. m. | −192 | Some clouds. |
| Sept. 29 | 9 45 a. m. | −193 | Clear. |
| Sept. 20 | 4 p. m. | −191 | Do. |
| Oct. 4 | 9 a. m. | −193 | Do. |
| | 4 p. m. | −194 | Do. |
| Oct. 5 | 7 30 a. m. | −197 | Do. |
| | 2 30 p. m. | −194 | Clouds. |
| Oct. 6 | 7 30 a. m. | −198 | Clear. |
| | 5 p. m. | −179 | Do. |
| Oct. 7 | 7 45 a. m. | −187 | Clear. |
| | 12 m. | −179 | Do. |
| | 3 15 p. m. | −182 | Do. |
| | 6 30 p. m. | −185 | Do. |
| Oct. 8 | 7 30 a. m. | −189 | Do. |
| | 4 p. m. | −183 | Do. |
| Oct. 9 | 7 30 a. m. | −187 | Cloudy. |
| | 3 30 p. m. | −185 | Do. |
| Oct. 10 | 8 a. m. | −187 | Do. |
| | 12 m. | −184 | Overcast. |
| | 4 p. m. | −184 | Do. |
| Oct. 11 | 8 15 a. m. | −185 | Cloudy for 2 days. |
| Oct. 12 | 8 a. m. | −188 | Cloudy; rainy since noon of 11th. |
| | 4 p. m. | −184 | Cloudy and sun. |
| Oct. 13 | 8 a. m. | −188 | Clear and cold. |
| | 2 p. m. | −184 | Do. |
| Oct. 14 | 8 a. m. | −188 | Do. |
| Oct. 16 | 9 a. m. | −188 | Cloudy. |
| | 4 p. m. | −185 | Do. |
| Oct. 17 | 8 a. m. | −188 | Cloudy; since 15th. |
| Oct. 18 | 8 a. m. | −190 | Clear. |
| Oct. 19 | 8 a. m. | −188 | Do. |
| | 4 p. m. | −182 | Do. |
| Oct. 20 | 7 30 a. m. | −187 | |
| | 2 p. m. | −183 | Clear. |
| Oct. 21 | 8 a. m. | −185 | Do. |
| Oct. 22 | 4 p. m. | −186 | Do. |
| Oct. 23 | 7 a. m. | −188 | Do. |
| | 11 a. m. | −186 | Do. |
| Oct. 24 | 7 p. m. | −190 | Clear. |
| | 12 m. | −187 | Do. |
| | 7 p. m. | −186 | Do. |
| Oct. 25 | 8 a. m. | −187 | Do. |
| Oct. 26 | 7 30 a. m. | −187 | Overcast. |
| Oct. 27 | 8 a. m. | −190 | Do. |
| | 4 p. m. | −189 | Clear. |
| Oct. 28 | 7 30 a. m. | −192 | Overcast. |
| | 4 p. m. | −190 | Do. |
| Oct. 29 | 2 p. m. | −189 | Clear. |
| Oct. 30 | 7 30 a. m. | −192 | Overcast. |
| Oct. 31 | 8 a. m. | −191 | Do. |
| Nov. 1 | 10 30 a. m. | −191 | Do. |
| Nov. 2 | 8 a. m. | −194 | Showers. |
| Nov. 3 | 9 a. m. | −196 | Clear. |
| Nov. 4 | 8 a. m. | −196 | Do. |
| | 4 p. m. | −194 | Do. |
| Nov. 5 | 8 a. m. | −197 | Do. |
| | 4 p. m. | −194 | Do. |
| Nov. 6 | 8 a. m. | −198 | Do. |
| | 3 p. m. | −195 | Do. |
| Nov. 7 | 8 a. m. | −198 | Do. |

TABLE 3—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Nov. 8 | 10h m a. m. | −194 | Clear. |
| Nov. 9 | 8 a. m. | −197 | Cloudy. |
| Nov. 10 | 4 p. m. | −143 | Do. |
| Nov. 11 | 7 30 a. m. | −194 | Raining. |
| | 4 p. m. | −193 | Do. |
| Nov. 12 | 8 a. m. | −195 | Cloudy. |
| Nov. 12 | 4 p. m. | −193 | Raining. |
| Nov. 13 | 7 30 a. m. | −197 | Clear. |
| Nov. 14 | 7 30 a. m. | −197 | Do. |
| | 4 p. m. | −193 | Do. |
| Nov. 15 | 8 a. m. | −195 | Do. |
| | 1 30 p. m. | −190 | Do. |
| | 6 p. m. | −192 | Cloudy. |
| Nov. 16 | 8 a. m. | −191 | Drizzle. |
| Nov. 17 | 7 30 a. m. | −195 | Clear. |
| Nov. 18 | 7 30 a. m. | −195 | Do. |
| | 11 30 a. m. | −188 | Do. |
| | 2 p. m. | −189 | Do. |
| | 7 p. m. | −190 | Do. |
| Nov. 19 | 7 30 a. m. | −192 | Do. |
| Nov. 20 | 8 a. m. | −192 | Do. |
| | 11 30 a. m. | −182 | Do. |
| | 2 p. m. | −183 | Do. |
| | 4 30 p. m. | −193 | Do. |
| Nov. 21 | 8 a. m. | −191 | Overcast. |
| | 12 m. | −185 | Slightly overcast. |
| | 4 p. m. | −185 | Overcast. |
| Nov. 22 | 8 a. m. | −191 | Clear. |
| Nov. 23 | 7 30 a. m. | −187 | Overcast. |
| Nov. 24 | 7 30 a. m. | −188 | Do. |
| | 2 p. m. | −185 | Clear. |
| Nov. 25 | 7 a. m. | −192 | Do. |
| | 2 p. m. | −187 | Hazy. |
| Nov. 26 | 12 m. | −186 | Do. |
| Nov. 27 | 8 a. m. | −190 | Clear. |
| Nov. 28 | 8 a. m. | −188 | Do. |

In the earlier part of the test the irregularities and wide range of suction may be attributed in part to faulty fittings. It is apparent, however, that the greatest suction might come at mid-day as determined by the tension on the water column. Much air was drawn from the stem at times. The low record during the first 20 days of July may be taken as being due to defective connections. When this fault was repaired an irregular increase of suction followed, which continued for 20 days, reaching a seasonal maximum of 213 mm. Hg. = 0.28 atm.

The capacity of the instrument having been reached a replacement was made and suction climbed to a maximum of −198 mm. Hg. in 56 days. It remained near this point to the close of the observations. The amount of suction must be attributed to the tension in the water column and its daily variations to the changes in pressure of the enclosed gases under the influence of temperature. This variation was especially notable in all tests on November 20, when the records in this tree were −192, 182 and 193, morning, noon and evening. A record of 198, 189 and 204 represents the maximum daily range of variation.

## SUCTION AND PRESSURE IN OUTER LAYERS OF TRUNKS OF LARGE PINE TREES.

This tree (*Pinus radiata*, No. 28, Dendrographic series) has been under dendrographic measurement since 1924 (fig. 7). The trunk had

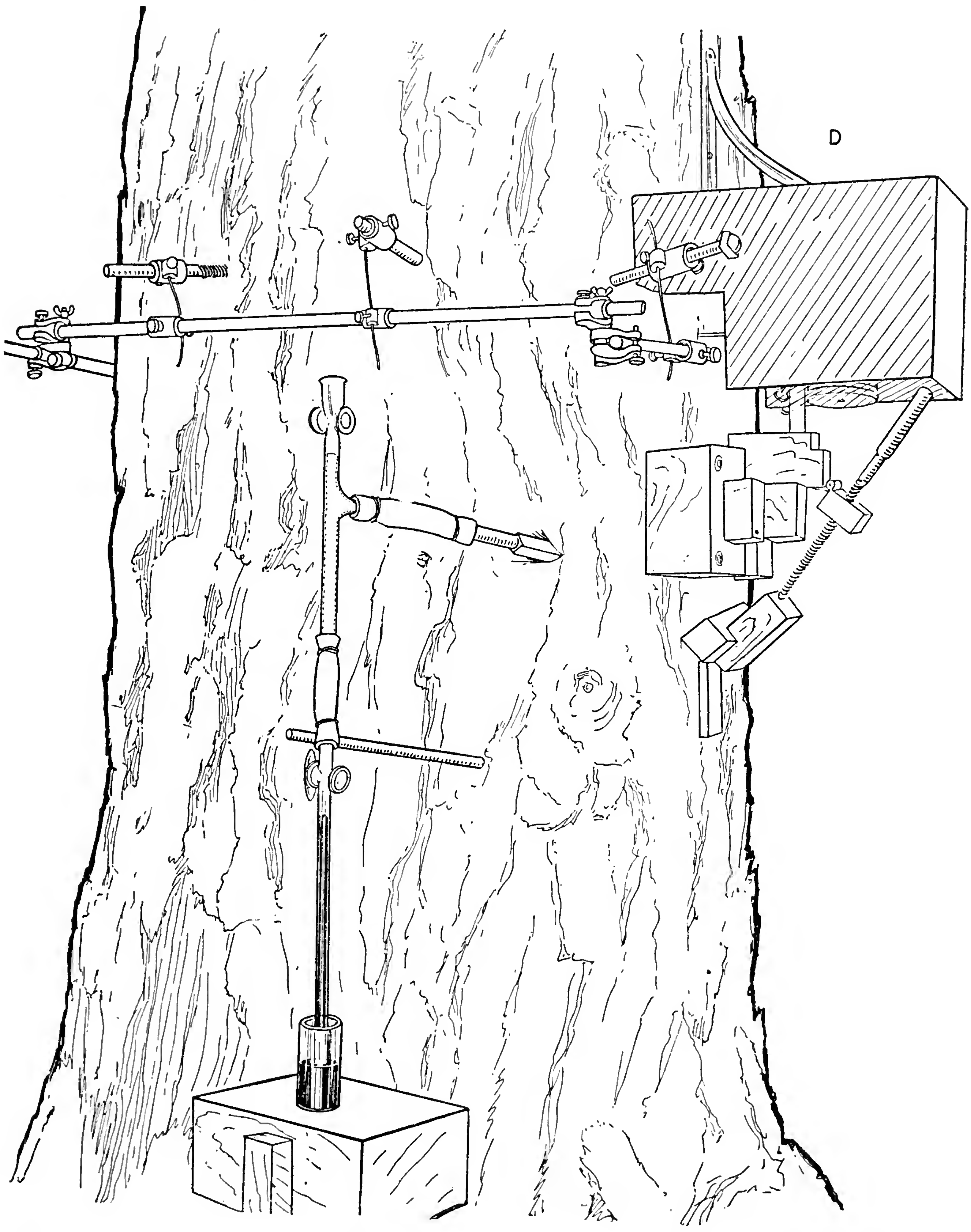



Fig. 7.—Monterey pine (No. 28 of Dendrographic series) with manometer attached to radial bore which tapped some older wood. Observations begun April 1925 and continued for 7 months. Suction as great as 0.5 atm. was registered.

a diameter of about 80 cm. and was approaching maturity. The layers of wood formed annually were not more than 1 to 2 mm. in thickness. No test could be made as to the hollow cylindrical column of ascending sap, but it may be safely assumed that a tangential bore driven to a depth of 8 cm. at a distance of 80 cm. from the base, con-

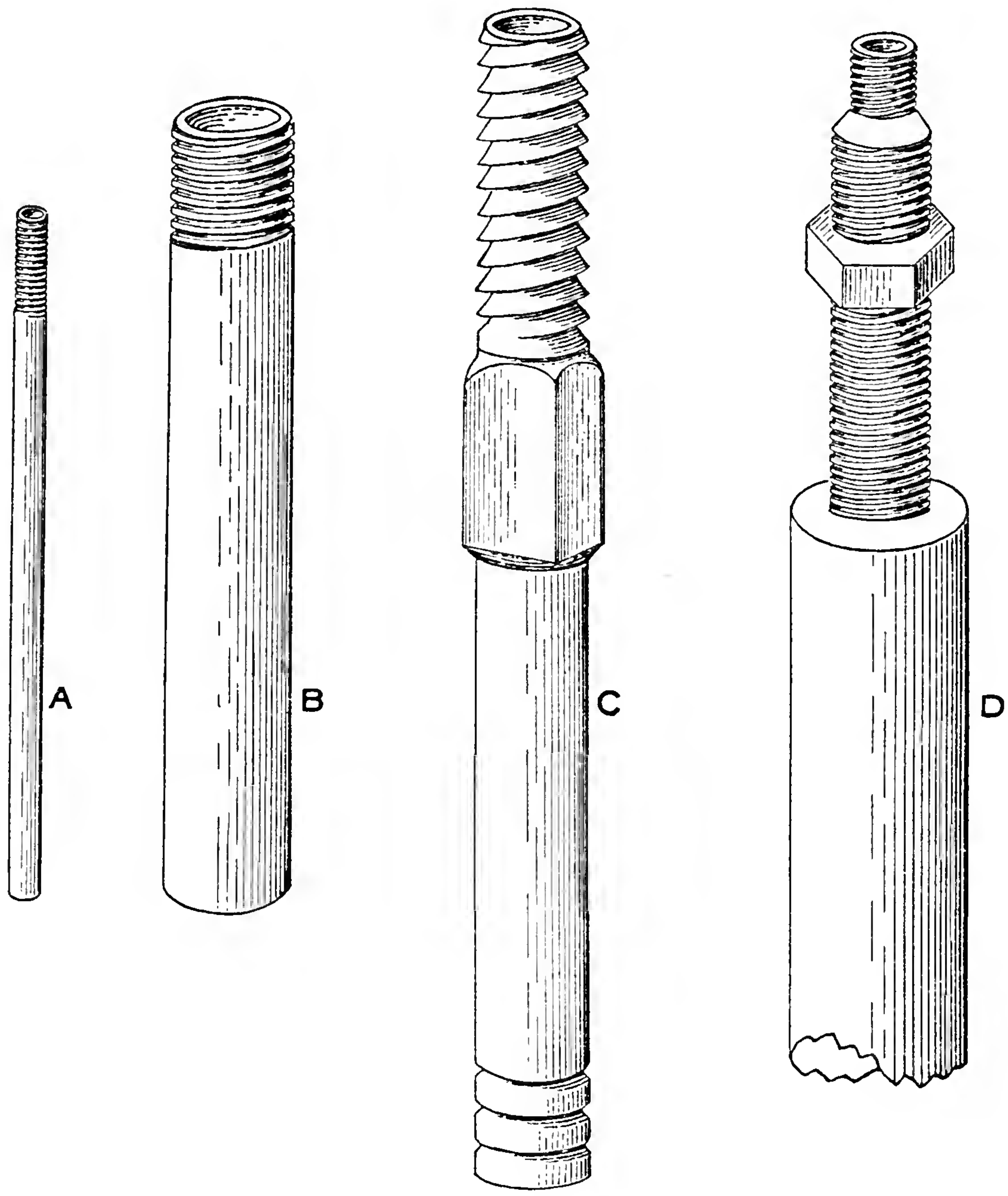



Fig. 8.—Threaded tubes used in bores for extraction of sap and for attachment of manometers. A, small tube for extracting sap from separate layers of wood of pine trees. D, larger tube with set nut collar for general extraction. B, section of brass tube with threaded end for general use in attachment of manometers to bores. C, tube with tapering threaded end for secure fixation in bores with square section to facilitate fixation by screwing firmly into bore.

nected not only the sap-carrying layer (fig. 1 B) but also the inner cylinder filled with air (fig. 1 D). The first manometer was of the type with closed end so that absorption pressure would be denoted by a shortened air-column, and suction by a lengthened one. Later, an open-arm manometer, then a single upright tube stepped in a dish of mercury, were used as noted. Readings were as shown in Table 4.

TABLE 4.

| Date. | Time. | Length of air-column in closed end of manometer in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Apr. 15 | $8^h05^m$ a. m. | 80 | In attachment of instrument a few minutes elapsed after water is poured into borehole before column could be measured. This error, however, could not amount to more than 1 to 2 mm. Hg. |
| | 8 08 a. m. | 83 | |
| | 8 10 a. m. | 84 | |
| | 8 15 a. m. | 85 | |
| | 8 25 a. m. | 85 | |
| | 8 30 a. m. | 85 | |
| | 8 45 a. m. | 87 | |
| | 9 a. m. | 88 | |
| | 9 30 a. m. | 88 | |
| | 12 m. | 87 | |
| | 2 30 p. m. | 68 | |
| Apr. 15 | 4 30 p. m. | 52 | |
| Apr. 16 | 8 a. m. | 26 | =3.2 atm. exudation pressure. |
| | 10 a. m. | 26 | |
| Apr. 17 | 8 a. m. | 26 | Refitted and cleaned out; not much resin; air-column 77 mm. |
| | 10 30 a. m. | 68 | Tube as in fig. 8 D screwed into bore. |
| | 2 p. m. | 67 | |
| | 3 p. m. | 67 | |
| Apr. 18 | 3 p. m. | 100 | Suction. |
| Apr. 19 | 9 a. m. | | |
| Apr. 20 | 9 a. m. | 100 | |
| Apr. 21 | 9 a. m. | 51 | |
| Apr. 22 | 9 a. m. | 50 | No significant variation in 20 days following. |
| July 4 | 4 p. m. | 150 | Much air in column, but liquid in cavity; new manometer with open arm fitted after replacing watery contents of bore which contained dense clumps of resinous material. |
| | | Suction or pressure in mm. Hg. | |
| July 4 | 4 15 p. m. | − 8 | Sunny. |
| July 5 | 8 30 a. m. | − 38 | Overcast; air released; set to 0. |
| | 10 30 a. m. | + 5 | Clear. |
| | 4 30 p. m. | − 5 | Do. |
| July 6 | 7 a. m. | − 30 | |
| | 11 a. m. | − 27 | Clear. |
| | 7 30 p. m. | − 39 | Do. |
| July 7 | 7 a. m. | − 62 | Overcast. |
| | 9 a. m. | − 63 | Do. |
| | 2 p. m. | − 62 | Sunny; air released; set at 0. |
| | 4 p. m. | − 3 | Sunny. |
| July 8 | 7 30 a. m. | − 6 | Overcast. |
| | 9 30 a. m. | − 3 | Clearing; air released, and reset to 0. |
| | 2 p. m. | − 5 | |
| | 4 p. m. | − 6 | Overcast. |
| July 9 | 7 30 a. m. | − 3 | Fog and drizzle. |
| | 10 30 a. m. | − 3 | Do. |
| | 4 p. m. | − 3 | Overcast. |
| July 11 | 7 30 a. m. | − 8 | Air released and set to 0. |
| | 11 a. m. | − 0 | Clear. |
| | 2 30 p. m. | − 7 | Do. |
| | 4 30 p. m. | − 12 | Do. |
| July 12 | 8 a. m. | − 33 | Do. |
| | 10 30 a. m. | − 32 | Do. |

TABLE 4—*Continued.*

| Date. | Time. | Suspension or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 13 | $7^h30^m$ a. m. | − 70 | Clear. |
| | 9 30 a. m. | − 72 | Do. |
| | 12 m. | − 74 | Do. |
| | 3 30 p. m. | − 78 | Do. |
| July 14 | 7 30 a. m. | −103 | Do. |
| | 11 15 a. m. | −108 | Alternating cloud and sunshine. |
| | 2 15 p. m. | −110 | Do. |
| July 15 | 7 30 a. m. | −138 | Foggy. |
| | 9 30 a. m. | −138 | Clear. |
| | 1 30 p. m. | −139 | Do. |
| July 16 | 7 a. m. | −116 | Do. |
| | 11 a. m. | −115 | Do. |
| | 3 30 p. m. | − 79 | Do. |
| July 17 | 7 a. m. | −105 | Do. |
| | 3 15 p. m. | − 75 | Do. |
| July 18 | 7 a. m. | − 66 | Clouds. |
| | 11 30 a. m. | − 63 | Do. |
| | 4 p. m. | − 55 | Do. |
| July 19 | 7 04 a. m. | − 35 | Clouds; air out; reset to 0. |
| | 10 a. m. | − 5 | |
| | 5 p. m. | − 18 | Cloudy. |
| July 20 | 7 a. m. | − 38 | Do. |
| | 11 30 a. m. | − 42 | Do. |
| | 3 30 a. m. | − 45 | Clear. |
| July 21 | 7 a. m. | − 60 | Overcast. |
| | 11 a. m. | − 74 | Do. |
| | 4 p. m. | − 84 | Clouds and sun. |
| July 22 | 7 a. m. | −103 | Drizzling. |
| | 11 a. m. | −107 | Do. |
| | 4 30 p. m. | −110 | Overcast. |
| July 23 | 8 a. m. | −127 | Do. |
| | 11 45 a. m. | −132 | Clear. |
| | 4 p. m. | −138 | Do. |
| July 24 | 7 30 a. m. | −160 | Cloudy. |
| | 4 p. m. | −172 | Clouds and sunshine. |
| | 8 p. m. | −174 | Limit of U tube. |
| July 25 | 7 30 a. m. | −182 | Overcast. |
| | 9 a. m. | −180 | Clear. |
| | 12 m. | −184 | Do. |
| | 3 p. m. | −184 | Clouds. |
| July 26 | 7 30 a. m. | −186 | U tube replaced by vertical column. Reset at −160. |
| | 10 a. m. | −148 | Overcast. |
| | 3 p. m. | −145 | Do. |
| July 27 | 7 30 a. m. | −158 | Do. |
| | 11 30 a. m. | −155 | Do. |
| | 2 30 p. m. | −160 | Do. |
| July 28 | 7 a. m. | −174 | Do. |
| | 11 a. m. | −174 | Do. |
| | 2 p. m. | −175 | Sunny. |
| July 29 | 7 45 a. m. | −195 | Overcast. |
| July 30 | 8 a. m. | −215 | Dripping fog. |
| | 4 p. m. | −212 | Overcast. |
| July 31 | 7 30 a. m. | −235 | Do. |
| | 11 30 a. m. | −232 | Clearing. |
| Aug. 2 | 4 p. m. | ......... | Connections faulty and were not restored until 5 days later, when stopcocks were left open and amount of water absorbed was measured. |
| Aug. 6 | 4 p. m. | ......... | Set at 0. |
| Aug. 7 | 4 p. m. | ......... | 2.5 ml. water absorbed. |
| Aug. 8 | 4 p. m. | ......... | 1.2 ml. water absorbed. |

TABLE 4—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 9 | $7^{h}$ $^{m}$ p. m. | ......... | 1.5 ml. water absorbed. |
| Aug. 10 | 4 p. m. | ......... | 1.2 ml. water absorbed. |
| | | | 6.4 ml. water absorbed in 96 hours. Stopcocks closed to measure suction. |
| Aug. 11 | 8 a. m. | −54 | |
| | 11 30 a. m. | −58 | Clear. |
| | 7 p. m. | −75 | Do. |
| Aug. 12 | 7 30 a. m. | −95 | Clear. |
| | 11 30 a. m. | −100 | Do. |
| | 4 15 p. m. | −112 | Do. |
| Aug. 13 | 7 30 a. m. | −138 | Overcast. |
| | 11 30 a. m. | −145 | Do. |
| | 7 p. m. | −160 | Sun in afternoon. |
| Aug. 14 | 5 45 a. m. | −177 | Overcast. |
| | 8 45 a. m. | −177 | Clearing. |
| Aug. 15 | 11 a. m. | −210 | Overcast. |
| Aug. 16 | 7 30 a. m. | −232 | Do. |
| | 4 p. m. | −245 | Do. |
| Aug. 17 | 7 30 a. m. | −256 | Do. |
| | 11 30 a. m. | −256 | Clear at $9^{h}30^{m}$. |
| | 4 p. m. | −293 | Clear. |
| Aug. 18 | 7 30 a. m. | −280 | Do. |
| | 11 a. m. | −275 | Do. |
| | 4 p. m. | −280 | Do. |
| Aug. 19 | 7 a. m. | −295 | Do. |
| | 11 45 a. m. | −262 | Do. |
| | 4 15 p. m. | −292 | Do. |
| Aug. 20 | 7 30 a. m. | −50 | Fittings defective. |
| Aug. 22 | 8 a. m. | −0 | Reset at −50. |
| Aug. 23 | 8 a. m. | −65 | Misting. |
| | 11 15 a. m. | −63 | Clearing. |
| | 4 30 p. m. | −70 | Clear. |
| Aug. 24 | 7 30 a. m. | −66 | Do. |
| | 11 30 a. m. | −63 | |
| | 4 p. m. | −72 | Do. |
| Aug. 25 | 7 30 a. m. | −75 | Do. |
| | 11 30 a. m. | −73 | Do. |
| | 4 p. m. | −78 | Do. |
| Aug. 26 | 8 a. m. | −92 | Overcast. |
| | 11 30 a. m. | −92 | Beginning to clear. |
| | 7 15 p. m. | −95 | Overcast. |
| Aug. 27 | 6 a. m. | −99 | |
| | 7 a. m. | −97 | |
| | 8 a. m. | −90 | |
| | 9 a. m. | −92 | |
| | 10 a. m. | −91 | |
| | 12 m. | −92 | |
| | 2 p. m. | −93 | |
| | 3 p. m. | −93 | |
| | 4 p. m. | −96 | |
| | 5 p. m. | −97 | |
| | 8 p. m. | −97 | |
| | 11 p. m. | −102 | |
| Aug. 28 | 3 a. m. | −103 | |
| | 4 a. m. | −105 | |
| | 6 a. m. | −104 | |
| | 8 a. m. | −100 | |
| | 9 a. m. | −97 | |
| | 10 a. m. | −97 | |
| | 11 a. m. | −98 | |

TABLE 4—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 28 | 2h m p. m. | − 96 | |
| | 4 p. m. | − 97 | |
| | 7 p. m. | − 99 | |
| | 9 p. m. | −101 | |
| Aug. 29 | 3 a. m. | −106 | |
| | 4 a. m. | −104 | |
| | 6 a. m. | −104 | |
| | 8 a. m. | −101 | |
| Aug. 30 | 9 a. m. | −104 | Fog and dew. |
| | 12 m. | − 97 | Clear. |
| | 6 p. m. | − 99 | |
| Aug. 31 | 9 a. m. | − 98 | |
| | 4 p. m. | − 94 | |
| Sept. 1 | 7 a. m. | −103 | Rain clouds. |
| | 9 a. m. | ......... | Fittings defective. U tube replaced by vertical column. Good connections to bore not restored until Sept. 21. |
| Sept. 21 | 4 p. m. | −145 | Clear. |
| Sept. 22 | 7 30 a. m. | −148 | Do. |
| | 11 30 a. m. | −147 | Do. |
| | 5 30 p. m. | −153 | Cloudy. |
| Sept. 23 | 8 a. m. | −163 | Do. |
| | 12 m. | −162 | Clear after 9 a. m. |
| | 4 p. m. | −166 | Cloudy. |
| Sept. 24 | 7 15 a. m. | −178 | Overcast. |
| | 11 30 a. m. | −178 | Clearing. |
| Sept. 24 | 4 p. m. | −179 | Clouds. |
| Sept. 25 | 8 a. m. | −192 | Clear. |
| | 5 p. m. | −194 | Do. |
| Sept. 26 | 7 15 a. m. | −206 | Do. |
| | 11 45 a. m. | −212 | Do. |
| | 4 p. m. | −214 | Do. |
| Sept. 28 | 7 30 a. m. | −228 | Some clouds. |
| Sept. 29 | 9 45 a. m. | −242 | Clear and cold. |
| Sept. 30 | 4 p. m. | −248 | Do. |
| Oct. 4 | 9 a. m. | −280 | Reset at −305 mm. |
| | 4 p. m. | −307 | Clear. |
| Oct. 5 | 7 30 a. m. | −312 | Do. |
| | 2 30 p. m. | −307 | Clouds. |
| Oct. 6 | 7 30 a. m. | −312 | Clear. |
| | 5 p. m. | −305 | Do. |
| Oct. 7 | 7 45 a. m. | −317 | Do. |
| | 12 m. | −303 | Do. |
| | 3 15 p. m. | −308 | Do. |
| | 6 30 p. m. | −317 | Do. |
| Oct. 8 | 7 30 a. m. | −322 | Clear and cold. |
| | 4 p. m. | −313 | Clear. |
| Oct. 9 | 7 30 a. m. | −324 | Cloudy. |
| | 3 30 p. m. | −296 | Air released; reset at −296. |
| Oct. 10 | 8 a. m. | −306 | Cloudy. |
| | 12 m. | −304 | Do. |
| | 4 p. m. | −306 | Do. |
| Oct. 11 | 8 a. m. | −313 | Do. |
| Oct. 12 | 8 a. m. | −324 | Cloudy. |
| | 4 p. m. | −320 | Clear. |
| Oct. 13 | 8 a. m. | −320 | Do. |
| | 2 p. m. | −322 | Do. |
| Oct. 14 | 8 a. m. | −330 | Do. |
| Oct. 16 | 9 a. m. | −332 | Cloudy. |
| | 4 p. m. | −380 | Do. |
| Oct. 17 | 9 a. m. | −333 | Do. |
| | 3 p. m. | −330 | Sun; air bubble out; reset at −290. |
| Oct. 18 | 8 a. m. | −302 | Clear. |
| Oct. 19 | 8 a. m. | −305 | Do. |
| | 4 p. m. | −288 | Do. |

TABLE 4—*Continued.*

| Date. | Time. | Suction or pressure in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Oct. 20 | $7^h30^m$ a. m. | −295 | Clear. |
| | 2 p. m. | −280 | Do. |
| Oct. 21 | 8 a. m. | −286 | Do. |
| Oct. 22 | 4 p. m. | −286 | Do. |
| Oct. 23 | 7 a. m. | −295 | Do. |
| | 11 a. m. | −288 | Do. |
| Oct. 24 | 7 a. m. | −296 | Do. |
| | 12 m. | −287 | Do. |
| | 7 p. m. | −290 | Do. |
| Oct. 25 | 8 a. m. | −292 | Do. |
| Oct. 26 | 7 30 a. m. | −292 | Do. |
| Oct. 27 | 8 a. m. | −300 | Overcast. |
| Oct. 28 | 7 30 a. m. | −305 | Do. |
| | 4 p. m. | −300 | Do. |
| Oct. 29 | 2 p. m. | −300 | Clear. |
| Oct. 30 | 7 30 a. m. | −312 | Overcast. |
| | 8 a. m. | −312 | Do. |
| Nov. 1 | 10 30 a. m. | −316 | Do. |
| Nov. 2 | 8 a. m. | −325 | Showers. |
| Nov. 3 | 9 a. m. | −330 | Clearing. |
| Nov. 4 | 8 a. m. | −331 | Do. |
| | 4 p. m. | −330 | Clear. |
| Nov. 5 | 8 a. m. | −338 | Do. |
| | 4 p. m. | −331 | Do. |
| Nov. 6 | 8 a. m. | −340 | Do. |
| | 3 p. m. | −332 | Do. |
| Nov. 7 | 8 a. m. | −340 | Do. |
| Nov. 8 | 10 a. m. | −332 | Do. |
| Nov. 9 | 8 a. m. | −341 | Do. |
| | 3 p. m. | −332 | Cloudy. |
| Nov. 10 | 4 p. m. | −337 | Do. |
| Nov. 11 | 7 30 a. m. | −338 | Raining. |
| | 4 p. m. | −338 | Do. |
| Nov. 12 | 8 a. m. | −340 | Cloudy. |
| | 4 p. m. | −336 | Raining. |
| Nov. 13 | 7 30 a. .m | −345 | Clear; air released; reset at −340. |
| Nov. 14 | 7 30 a. m. | −340 | Clear. |
| | 4 p. m. | −334 | Do. |
| Nov. 15 | 8 a. m. | −340 | Do. |
| | 1 30 p. m. | −331 | Do. |
| | 6 p. m. | −338 | Cloudy. |
| Nov. 16 | 8 a. m. | −336 | Drizzle. |
| Nov. 17 | 7 30 a. m. | −341 | Clear. |
| Nov. 18 | 7 30 a. m. | −342 | Clear. |
| | 11 30 a. m. | −333 | Do. |
| | 2 p. m. | −332 | Do. |
| | 7 p. m. | −338 | Do. |
| Nov. 19 | 7 30 a. m. | −340 | Do. |
| Nov. 20 | 8 a. m. | −310 | Clear; no air drawn out; leaking. |

The expected positive pressure was illustrated by the records of the first two days when a maximum of 3.2 atmospheres was observed. Positive pressure on one day in July was an erratic occurrence for which no explanation can be offered. Variations in which suction was greatest at mid-day were seen in the earlier part of the record, to be followed by the cycle in which it was least at the time of the greatest

expansion of the included gases. Here, as in other trees, when the instrument was reset at 0, suction climbed slowly to a maximum, which was −345 mm. Hg. = 0.45 atmospheres for the season, near which amount it stood for some time. Mid-day decreases did not exceed 15 mm. Hg., but greater changes might ensue in general increase of suction in a day.

Something of the nature of the suction was disclosed by measurements of the amount of water which might be taken in through the bore.

On August 6 to 10, 6.4 ml. were absorbed. The higher initial rate may be ascribed to combined action of capillarity and tension in the water-column. Later, after the capillary extension of the water had reached its limit, the rate indicated that of the pull transmitted from the leaves.

A sudden variation by which suction decreased from −292 mm. Hg. to −50 over night on August 20 may not be attributed entirely to defective joints found 2 days later, as a second occurrence of this began on November 20, and similar observations have been made on the oak.

Records of the variations in diameter of the *Pinus radiata*, No. 6 (Dendrographic series), have been made since March 1920. It is about 22 to 24 years old, and has a diameter of 22 cm. near the base. An 8-mm. bore was driven tangentially in the trunk about 80 cm. above the base, to which a manometer with a closed arm was fitted at first, to be replaced by other instruments later as noted. The readings of the first instrument give the length of the air-column in the closed end under compression denoting exudation pressure, and extension denoting suction (fig. 9). The bore probably opened into the central cylinder (fig. 1 D) and the sap-carrying layer (fig. 1 B).

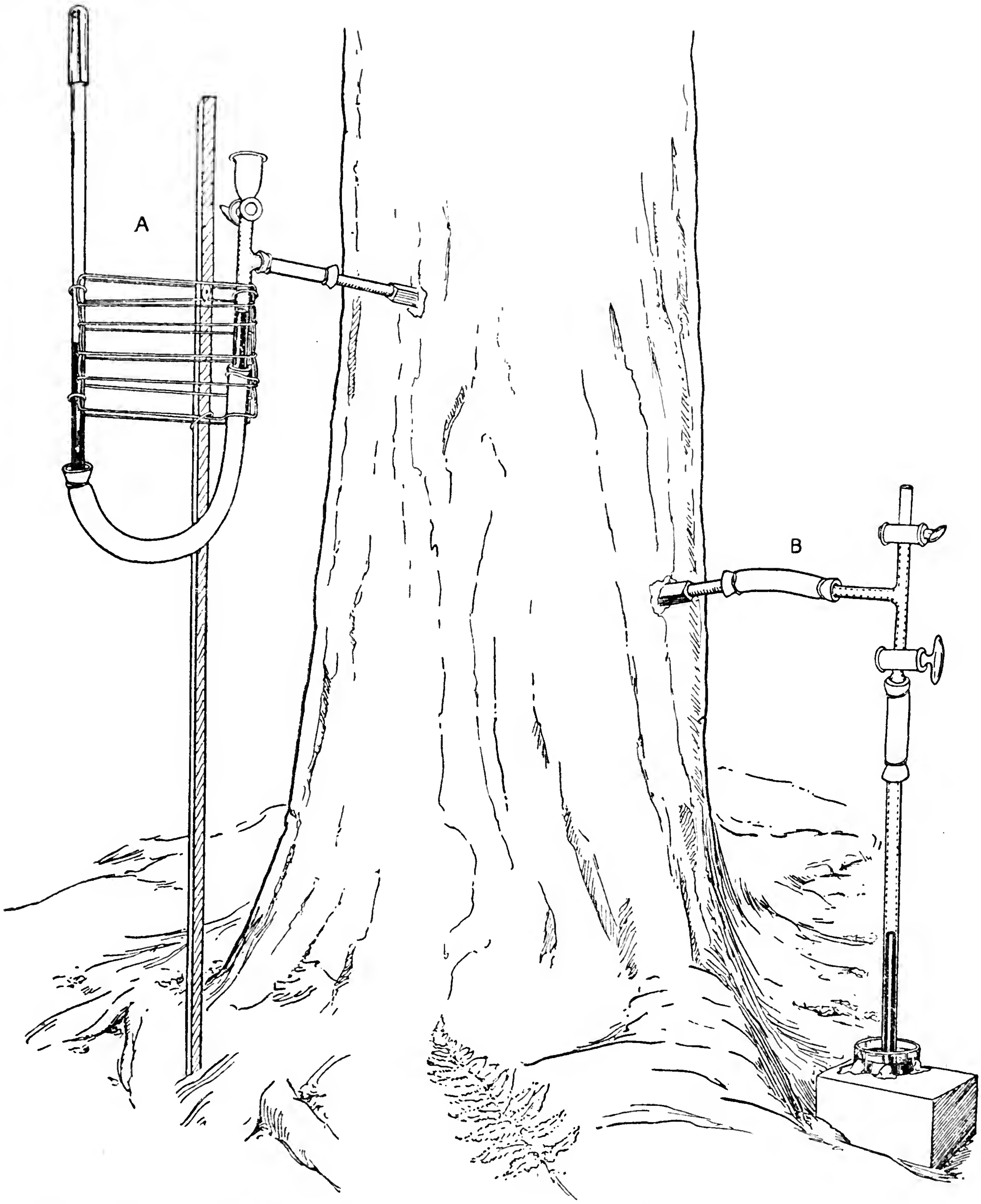



FIG. 9.—Manometers attached to Monterey pine (No. 6 Dendrographic series). U manometer on left is attached to a tangential bore in which pressure was measured April-November 1925. Manometer with vertical tube on right is attached to radial bore on which observations were made for a few days only.

TABLE 5.

| Date. | Time. | Length of air-column in mm. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Apr. 15 | $3^h55^m$ p. m. | 80 | |
| | 4 p. m. | 81 | |
| | 4 10 p. m. | 80 | |
| | 4 30 p. m. | 78 | |
| Apr. 16 | 8 a. m. | 45 | |
| | 10 a. m. | 48 | |
| Apr. 17 | 8 a. m. | 43 = 1.9 atm. | |
| | 10 30 a. m. | 44 | |
| | 2 p. m. | 45 | |
| | 3 p. m. | 67 | |
| Apr. 18 | 3 p. m. | 47 | |
| Apr. 19 | 9 a. m. | 42 | |
| Apr. 20 | 9 a. m. | 45 | |
| Apr. 21 | 9 a. m. | 48 | |
| Apr. 22 | 9 a. m. | 52 | |
| Apr. 23 | 9 a. m. | 54 | |
| Apr. 24 | 9 a. m. | 56 | |
| Apr. 25 | 10 30 a. m. | 58 | |
| Apr. 26 | 10 a. m. | 61 | |
| Apr. 27 | 10 a. m. | 67 | |
| Apr. 28 | 9 30 a. m. | 69 | |
| Apr. 29 | 9 15 a. m. | 73 | |
| Apr. 30 | 9 30 a. m. | 77 | |
| May 1 | 9 40 a. m. | 74 | |
| May 2 | 9 10 a. m. | 81 | |
| May 3 | 10 15 a. m. | 86 | |
| May 4 | 9 30 a. m. | 84 | |
| May 5 | 9 45 a. m. | 82 | |
| May 6 | 9 10 a. m. | 84 | |
| May 7 | 9 a. m. | 86 | |
| May 8 | 9 a. m. | 87 | |
| May 9 | 9 10 a. m. | 88 | |
| May 10 | 9 15 a. m. | 89 | |
| May 11 | 9 20 a. m. | 89 | |
| May 14 | 2 a. m. | 83 | Refitted; resinous material in liquid condition. |
| May 15 | 8 a. m. | 77 | |
| May 16 | 8 a. m. | 70 | |
| | 3 p. m. | 73 | |
| May 17 | 8 a. m. | 74 | |
| | 3 30 p. m. | 78 | |
| May 18 | 8 a. m. | 80 | No significant variation in following 37 days, and fittings became imperfect. Bore cleaned and refitted with larger tube of type shown in fig. 8 C. |
| July 2 | 9 a. m. | 102 = 0 | |
| | 9 30 a. m. | 98 | |
| | 11 a. m. | 80 | Exudation pressure = 1.26 atm. |
| | 7 p. m. | 100 | |
| July 3 | 7 a. m. | 112 | |
| | 8 30 a. m. | 110 | |
| | 11 a. m. | 110 | |
| | 2 30 p. m. | 112 | |
| | 5 p. m. | 114 | |
| July 4 | 9 a. m. | 113 | |
| | 11 a. m. | 113 | |
| | 3 30 p. m. | 113 | |
| July 5 | 8 30 a. m. | 115 | |
| | 10 30 a. m. | 115 | Clear. |
| | 4 30 p. m. | 115 | Do. |
| July 6 | 7 a. m. | 115 | Do. |
| | 11 a. m. | 114 | Do. |
| | 6 30 p. m. | 117 | Do. |

TABLE 5—*Continued.*

| Date. | Time. | Length of air-column in mm. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 7 | $7^h$ $^m$ a. m. | 115 | Overcast. |
| | 9 a. m. | 115 | Do. |
| | 2 p. m. | 115 | Clear. |
| | 4 p. m. | 117 | Do. |
| July 8 | 7 30 a. m. | 117 | Overcast. |
| | 9 30 a. m. | 117 | Clearing. |
| | 2 p. m. | 117 | Clear. |
| | 4 p. m. | 117 | Overcast. |
| July 9 | 7 30 a. m. | 118 | Fog and drizzle. |
| | 10 30 a. m. | 116 | Do. |
| | 4 p. m. | 117 | Overcast. |
| July 11 | 7 30 a. m. | 115 | Clear. |
| | 11 a. m. | 115 | Do. |
| | 2 30 p. m. | 115 | Do. |
| | 3 15 p. m. | 115 | Reset, after cleaning out bore, at 102. |
| | 4 30 p. m. | 106 | |
| July 12 | 8 a. m. | 110 | Clear. |
| | 10 30 a. m. | 110 | |
| July 13 | 7 30 a. m. | 114 | |
| | 9 30 a. m. | 115 | |
| | 12 m. | 114 | |
| July 14 | 7 30 a. m. | 115 | Clear. |
| | 11 30 a. m. | 116 | Do. |
| | 2 15 p. m. | 117 | Do. |
| July 15 | 7 30 a. m. | 117 | Foggy. |
| | 9 30 a. m. | 117 | Clear. |
| | 1 30 p. m. | 117 | Do. |
| July 16 | 7 a. m. | 117 | Do. |
| | 11 a. m. | 117 | Do. |
| | 3 30 p. m. | 118 | Do. |
| July 17 | 7 a. m. | 118 | Do. |
| | 3 15 p. m. | 119 | Do. |
| July 18 | 7 a. m. | 117 | Do. |
| | 11 30 a. m. | 118 | Clouds. |
| | 4 p. m. | 117 | Do. |
| July 19 | 7 40 a. m. | 117 | Do. |
| | 10 a. m. | 115 | Clouds. |
| | 5 p. m. | 116 | Cloudy. |
| July 20 | 7 a. m. | 110 | Do. |
| | 11 30 a. m. | 114 | Clouds. |
| | 3 30 p. m. | 112 | Clear. |
| July 21 | 7 a. m. | 113 | Overcast. |
| | 11 a. m. | 112 | Do. |
| | 4 p. m. | 113 | Clouds and sun. |
| July 22 | 7 a. m. | 110 | Drizzling. |
| | 4 30 p. m. | 110 | Overcast. |
| July 23 | 8 a. m. | 108 | Do. |
| | 11 45 a. m. | 108 | Clear. |
| | 4 p. m. | 113 | Do. |
| July 24 | 7 30 a. m. | 108 | Cloudy. |
| | 4 p. m. | 108 | Clouds and sunshine. |
| | 8 p. m. | 108 | |
| July 25 | 7 30 a. m. | 106 | Overcast. |
| | 9 a. m. | 108 | Clear. |
| | 12 m. | 108 | Do. |
| | 3 p. m. | 107 | Clouds. |
| July 26 | 7 30 a. m. | 106 | Fog. |
| | 10 a. m. | 106 | Overcast. |
| | 3 p. m. | 106 | Do. |
| July 27 | 7 a. m. | | |
| | 11 30 a. m. | 105 | Do. |
| | 2 30 p. m. | 105 | Do. |

TABLE 5—*Continued.*

| Date. | Time. | | Length of air-column in mm. | Remarks. |
|---|---|---|---|---|
| 1925 | | | | |
| July 28 | $7^h$ $^m$ | a. m. | 106 | Overcast. |
| | 11 | a. m. | 105 | Do. |
| July 28 | 2 | p. m. | 105 | Sunny. |
| July 29 | 7 40 | a. m. | 106 | Overcast. |
| July 30 | 8 | a. m. | 105 | Dripping fog. |
| | 4 | p. m. | 105 | Overcast. |
| July 31 | 7 30 | a. m. | 106 | Do. |
| | 11 30 | a. m. | 106 | Sun coming out. |
| Aug. 2 | 3 45 | p. m. | 106 | Do. |
| Aug. 3 | 7 30 | a. m. | .......... | Overcast. |
| | 11 30 | a. m. | 105 | Sunshine. |
| | 3 45 | p. m. | 105 | Do. |
| Aug. 4 | 8 | a. m. | 105 | Overcast. |
| | 2 30 | p. m. | 105 | Sunny. |
| Aug. 5 | 9 | a. m. | 107 | Fog. |
| Aug. 6 | 2 30 | p. m. | 107 | Clear. |
| Aug. 7 | 9 | a. m. | 105 | Fog. |
| | 4 | p. m. | 106 | Clear. |
| Aug. 8 | 8 | a. m. | 105 | Fog. |
| | 4 | p. m. | 105 | |
| Aug. 9 | 8 30 | a. m. | 104 | Overcast. |
| | 7 | p. m. | 108 | |
| Aug. 10 | 8 | a. m. | 105 | Overcast. |
| | 11 | a. m. | 104 | Sunny. |
| | 4 | p. m. | 107 | Air released; reset to 0 103. |
| Aug. 11 | 8 | a. m. | 104 | Sunny. |
| | 11 30 | a. m. | 106 | Do. |
| | 7 30 | p. m. | 107 | Do. |
| Aug. 12 | 7 30 | a. m. | 103 | Do. |
| | 11 | a. m. | 103 | Do. |
| | 4 15 | p. m. | 104 | Do. |
| Aug. 13 | 7 30 | a. m. | 106 | Overcast. |
| | 11 30 | a. m. | 107 | Do. |
| | 7 | p. m. | 108 | Sun in afternoon. |
| Aug. 14 | 5 45 | a. m. | 105 | Overcast. |
| | 8 45 | a. m. | 104 | Clearing. |
| Aug. 15 | 11 | a. m. | 107 | Overcast. |
| Aug. 16 | 7 30 | a. m. | 108 | Do. |
| | 4 | p. m. | 109 | Do. |
| Aug. 17 | 7 30 | a. m. | 109 | Do. |
| | 11 30 | a. m. | 108 | Clear. |
| | 4 | p. m. | 108 | Do. |
| Aug. 18 | 7 30 | a. m. | 103 | Do. |
| | 11 | a. m. | 102 | Do. |
| | 4 | p. m. | 105 | Do. |
| Aug. 19 | 7 | a. m. | 105 | |
| | 11 45 | a. m. | 104 | |
| | 4 15 | p. m. | 105 | |
| Aug. 20 | 7 30 | a. m. | 104 | |
| | 11 30 | a. m. | 104 | |
| Aug. 21 | 3 30 | p. m. | 105 | Fitting of tube to bore made secure and closed manometer replaced by arrangement similar to fig. 9 B. |
| | | | Suction in mm. Hg. | |
| Aug. 22 | 3 | p. m. | .......... | |
| | 5 | p. m. | − 10 | |
| Aug. 23 | 8 | a. m. | − 22 | Misting. |
| | 11 | a. m. | − 20 | Clearing. |

TABLE 5—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 23 | 4h m p. m. | − 20 | Clearing. |
| Aug. 24 | 7 30 a. m. | − 22 | Clear. |
| | 11 30 a. m. | − 18 | Do. |
| | 4 p. m. | − 23 | Do. |
| Aug. 25 | 7 30 a. m. | − 25 | Warm and clear. |
| | 11 30 a. m. | − 22 | Do. |
| | 4 p. m. | − 25 | Do. |
| Aug. 26 | 8 a. m. | − 25 | Overcast. |
| | 11 30 a. m. | − 27 | Beginning to clear. |
| | 7 15 p. m. | − 28 | Overcast. |
| Aug. 27 | 6 a. m. | − 30 | |
| | 7 a. m. | − 30 | |
| | 8 a. m. | − 27 | |
| | 9 a. m. | − 25 | |
| | 10 a. m. | − 22 | |
| | 11 a. m. | − 16 | |
| | 12 m. | − 10 | |
| | 2 p. m. | − 5 | |
| | 3 p. m. | − 0 | |
| | 4 p. m. | − 0 | |
| | 5 p. m. | − 0 | |
| | 8 p. m. | − 0 | |
| Aug. 28 | 10 a. m. | ........ | Reset with U-tube manometer. |
| | 11 a. m. | − 6 | |
| | 2 a. m. | − 8 | |
| | 4 a. m. | − 8 | |
| | 7 a. m. | − 11 | |
| | 9 a. m. | − 13 | |
| Aug. 29 | 3 a. m. | − 12 | |
| | 4 a. m. | − 17 | |
| | 6 a. m. | − 15 | |
| | 8 a. m. | − 15 | |
| Aug. 30 | 9 a. m. | − 21 | Fog and dew. |
| | 12 m. | − 20 | Sunny. |
| | 6 p. m. | − 21 | Overcast. |
| Aug. 31 | 9 a. m. | − 25 | Sunny. |
| | 4 p. m. | − 26 | Do. |
| Sept. 1 | 7 a. m. | − 32 | Rain-clouds. |
| | 12 m. | − 27 | Sunny. |
| | 7 p. m. | − 35 | Clear. |
| Sept. 2 | 7 a. m. | − 30 | Clearing. |
| | 11 a. m. | − 28 | Clear. |
| Sept. 5 | 11 a. m. | − 17 | Do. |
| | 6 30 p. m. | − 17 | Do. |
| Sept. 6 | 8 30 a. m. | − 12 | Clearing after shower. |
| | 10 a. m. | ......... | Instrument adjusted and set at 0. |
| | 6 p. m. | − 8 | Clouds. |
| Sept. 7 | 7 30 a. m. | − 17 | |
| | 11 15 a. m. | − 13 | Clear. |
| | 4 30 p. m. | − 24 | Do. |
| Sept. 8 | 7 30 a. m. | − 22 | Do. |
| | 11 30 a. m. | − 25 | Do. |
| | 4 p. m. | − 29 | Do. |
| Sept. 9 | 8 a. m. | − 36 | Cloudy since early morning. |
| | 11 30 a. m. | − 34 | Clear. |
| Sept. 10 | 7 30 a. m. | − 35 | Cloudy. |
| Sept. 13[1] | 8 a. m. | − 60 | Clearing. |
| | 11 a. m. | ......... | |
| | 6 p. m. | − 62 | Clear. |

[1] A bore 10 mm. in diameter was driven radially into trunk at lower level and fitted with a tube, fig. 8 B, connecting with a vertical capillary tube (see fig. 9 B). No water was put into system, and resinous exudate was collected until Sept. 22, when tubes were cleaned and filled with water in usual manner. Readings (page 40) were obtained from this radial bore for comparison with those from the tangential. Various defects were encountered so that no records of value were obtained until Sept. 28.

TABLE 5—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| Sept. 14 | 7 15 a. m. | − 65 | Clear. |
| | 11 30 a. m. | − 62 | Do. |
| | 4 p. m. | − 64 | Do. |
| Sept. 15 | 7 15 a. m. | − 68 | Do. |
| | 3 30 p. m. | − 57 | Do. |
| Sept. 16 | 7 30 a. m. | − 73 | Clear; some clouds. |
| Sept. 18 | 7 a. m. | − 84 | Clouds; rain on 17th. |
| Sept. 20 | 9 a. m. | − 55 | Clear. |
| Sept. 21 | 7 30 a. m. | − 57 | Do. |
| | 11 30 a. m. | − 50 | Do. |
| | 4 p. m. | − 56 | Do. |
| Sept. 22 | 7 30 a. m. | − 54 | Do. |
| | 11 30 a. m. | − 50 | Do. |
| | 5 30 p. m. | − 57 | Cloudy since 5 p. m. |
| Sept. 23 | 8 a. m. | − 64 | Cloudy. |
| | 12 m. | − 61 | Do. |
| | 4 p. m. | − 63 | Do. |

| Date. | Time. | Suction in mm. Hg. | | Remarks. |
|---|---|---|---|---|
| | | Tangential. | Radial. | |
| Sept. 24 | 7 15 a. m. | − 49 | | Clearing. |
| | 11 30 a. m. | − 50 | | Clouds. |
| | 4 p. m. | − 51 | | Clear. |
| Sept. 25 | 8 a. m. | − 53 | | Do. |
| | 5 p. m. | − 54 | | Do. |
| Sept. 26 | 7 15 a. m. | − 61 | | Do. |
| | 11 45 a. m. | − 53 | | Do. |
| | 4 p. m. | − 56 | | Clouds. |
| Sept. 28 | 7 30 a. m. | − 48 | −10 | Clear. |
| Sept. 29 | 9 45 a. m. | − 25 | −17 | Do. |
| Sept. 30 | 4 p. m. | − 38 | −24 | Do. |
| Oct. 4 | 9 a. m. | − 44 | −42 | Do. |
| | 4 p. m. | − 44 | −42 | Do. |
| Oct. 5 | 7 30 a. m. | − 47 | −45 | Clouds. |
| | 2 30 p. m. | − 39 | −33 | Clear. |
| Oct. 6 | 7 30 a. m. | − 47 | −42 | Do. |
| | 5 p. m. | − 44 | −48 | Do. |
| Oct. 7 | 7 45 a. m. | − 54 | −46 | Do. |
| | 12 m. | − 45 | −42 | Do. |
| | 3 15 p. m. | − 45 | −46 | Do. |
| | 6 30 p. m. | − 51 | −51 | Do. |
| Oct. 8 | 7 30 a. m. | − 66 | −54 | |
| | 4 p. m. | − 55 | −44 | Do. |
| Oct. 9 | 7 30 a. m. | − 63 | −54 | Cloudy. |
| | 3 30 p. m. | − 66 | −56 | Do. |
| Oct. 10 | 8 a. m. | − 66 | −56 | Do. |
| | 12 m. | − 66 | −54 | Cloudy. |
| | 4 p. m. | − 67 | −58 | Do. |
| Oct. 11 | 8 a. m. | − 72 | −63 | Do. |
| Oct. 12 | 8 a. m. | − 90 | −70 | Raining since noon. |
| | 4 p. m. | − 78 | −66 | |
| Oct. 13 | 8 a. m. | − 90 | −74 | Clouds and sun. |
| | 2 p. m. | − 78 | −66 | Do. |
| Oct. 14 | 8 a. m. | − 90 | −79 | Clear. |
| Oct. 16 | 9 a. m. | − 95 | −84 | Cloudy. |
| | 4 p. m. | − 94 | −84 | Do. |
| Oct. 17 | 9 a. m. | − 96 | −87 | Do. |
| Oct. 18 | 8 p. m. | − 98 | −90 | Clear. |
| Oct. 19 | 9 a. m. | − 81 | −90 | |
| | 4 p. m. | − 68 | Discontinued | |

Table 5—*Continued.*

| Date. | Time. | Suction in mm. Hg. Tangential. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Oct. 20 | $7^h30^m$ a. m. | − 78 | Clear. |
| | 2 p. m. | − 69 | Do. |
| Oct. 21 | 8 a. m. | − 62 | Do. |
| Oct. 22 | 4 p. m. | − 68 | Do. |
| Oct. 23 | 7 a. m. | − 78 | Do. |
| | 11 a. m. | − 72 | Do. |
| Oct. 24 | 7 p. m. | − 68 | Do. |
| | 12 m. | − 56 | Do. |
| | 7 p. m. | − 62 | Do. |
| Oct. 25 | 8 a. m. | − 42 | Do. |
| Oct. 26 | 7 30 a. m. | − 48 | Clear; air in tube. |
| Oct. 27 | 8 a. m. | − 43 | Overcast. |
| | 4 p. m. | − 41 | Clear. |
| Oct. 28 | 7 30 a. m. | − 42 | Overcast. |
| | 4 p. m. | − 38 | Do. |
| Oct. 29 | 2 p. m. | − 30 | Clear. |
| Oct. 30 | 7 30 a. m. | − 44 | Overcast. |
| Oct. 31 | 8 a. m. | − 43 | Do. |
| Nov. 1 | 10 30 a. m. | − 48 | Do. |
| Nov. 2 | 8 a. m. | − 56 | Showers. |
| Nov. 3 | 9 a. m. | − 60 | Clearing. |
| Nov. 4 | 8 a. m. | − 46 | Do. |
| | 4 p. m. | − 50 | Do. |
| Nov. 5 | 8 a. m. | − 62 | Clear. |
| | 4 p. m. | − 54 | Do. |
| Nov. 6 | 8 a. m. | − 68 | Do. |
| | 3 p. m. | − 60 | Do. |
| Nov. 7 | 8 a. m. | − 68 | Do. |
| Nov. 8 | 10 a. m. | − 48 | Do. |
| Nov. 9 | 8 a. m. | − 68 | Do. |
| | 3 p. m. | − 57 | Cloudy. |
| Nov. 10 | 4 p. m. | − 64 | Do. |
| Nov. 11 | 7 30 a. m. | − 67 | Raining. |
| | 4 p. m. | − 67 | Do. |
| Nov. 12 | 8 a. m. | − 74 | Cloudy. |
| | 4 p. m. | − 68 | Raining. |
| Nov. 13 | 7 30 a. m. | − 81 | Clear. Air released; reset at −75. |
| Nov. 14 | 7 30 p. m. | − 84 | Clear. |
| | 4 p. m. | − 80 | Do. |
| Nov. 15 | 8 a. m. | − 54 | Do. |
| | 1 30 p. m. | − 51 | Do. |
| Nov. 15 | 4 p. m. | − 56 | Cloudy. |
| Nov. 16 | 8 a. m. | − 59 | Drizzle. |
| Nov. 17 | 7 30 a. m. | − 68 | Clear. |
| Nov. 18 | 7 30 a. m. | − 72 | Do. |
| | 11 30 a. m. | − 66 | Do. |
| | 2 p. m. | − 66 | Do. |
| | 7 p. m. | − 69 | Do. |
| Nov. 19 | 7 30 a. m. | − 75 | Do. |
| Nov. 20 | 8 a. m. | − 80 | Do. |
| | 11 30 a. m. | − 70 | Do. |
| | 2 p. m. | − 68 | Do. |
| | 4 30 p. m. | − 75 | Do. |
| Nov. 21 | 8 a. m. | − 83 | Overcast. |
| | 12 m. | − 75 | Slightly overcast. |
| | 4 p. m. | − 78 | Overcast. |
| Nov. 22 | 8 a. m. | − 87 | Clear. |
| Nov. 23 | 7 30 a. m. | − 85 | Overcast. |
| Nov. 24 | 7 30 a. m. | − 92 | Do. |
| | 2 p. m. | − 90 | Clear. |
| Nov. 25 | 7 a. m. | −103 | Do. |
| | 2 p. m. | − 98 | Hazy. |
| Nov. 26 | 12 m. | −103 | Do. |
| Nov. 27 | 8 a. m. | −111 | Clear. |
| Nov. 28 | 8 a. m. | −114 | Do. |

The exudation and suction in this tree did not reach the maxima shown by No. 28. Positive pressures in the tangential bore amounting to 1.9 atmospheres were seen on the second day of the test, but suction was seen again in a refitted instrument nearly 3 months later. Daily variations were as in No. 28, the mid-day decrease not exceeding 12 mm. Hg. in any case. The measurements from the radial bore were indecisive, and are indicative of passages blocked by resinous material.

Suction in these tests may be attributed to the pull of the leaves on the continuous water column and the maximum of 90 mm. Hg. = 0.12 atmospheres was reached in October.

## NATURE OF EXUDATION PRESSURE OF THE PINE.

The registration of comparatively high exudation pressures in the recently formed wood of the Monterey pine has been previously described.[1] Bores driven tangentially in trees of all ages which formed heavy wood-layers became the seat of positive pressures which might amount to as much as 4 atmospheres.[2]

In repetition of these experiments, an apparatus consisting of a threaded brass tube connected by heavy rubber tubing with a manometer with closed end and with stopcock and filling funnel was attached to a tangential bore in Monterey pine No. 1 (Dendrographic series). Readings in terms of the length of the column of air in the closed end of the manometer were made (Table 6).

Another demonstration of exudation pressure was found by fixing a section of brass tubing in a shallow radial bore of a pine trunk 12 cm. in diameter on June 14, 1923, and making connection with an open U tube containing mercury. The connecting tube and bore were filled with water. The test was begun at 4 p. m. An hour later an exudation pressure of 12 mm. Hg. was shown. The next morning, 15 hours after beginning, a positive pressure of 38 mm. Hg. was seen—air had been forced out of the wood. This was released and the column set at 0 at 7 a. m. At 10 a. m. a positive pressure of 16 mm. Hg. had been set up. The following records were made in continuation of those given in Table 6.

A copious exudation of resin had taken place. Had a closed manometer been used, high pressures would doubtless have been recorded.

From these results and those obtained from bores and stumps of other individuals it is seen that positive or exudation pressures are exhibited by the pines only when bores are driven into the more recently formed wood and when surfaces are exposed from which resinous material exudes copiously. This has also been noted in a branch 22 cm. in diameter in 1924,[3] and in 1925 by the stump of a detached root

[1] MacDougal, D. T. Reversible variations in volume, pressure, and movements of sap in trees. Pub. 365, Carnegie Inst. Wash., 1925. See pp. 45–58.

[2] MacDougal, D. T. Absorption and exudation pressures of sap in plants. Proc. Amer. Phil. Soc., 64, 102–130, 1925.

[3] Publ. 365, Carnegie Inst. Wash., p. 54, 1925.

as well as on the terminus of the larger part of the root. In neither of these cases was the pressure more than that of a few mm. Hg. when measured in an open manometer. The maximum is attained within 2 days, then gradually declines. Removal of resin from the bore and freshening the surfaces is followed by a slight renewal of action. It is only when closed manometers with small bores are used that high pressures are developed. By the use of short thin air-columns an increase of 1 to 3 ml. of material to the contents of the bore may set up pressures of 4 atmospheres which soon decline.

TABLE 6.

| Date. | Time. | Length of air-column. | Remarks. |
|---|---|---|---|
| 1925. | | *mm.* | |
| Apr. 14 | $4^h00^m$ p. m. | 110 | Borehole tangential to wood of 1923. |
| | 4 20 p. m. | 115 | Suction or absorption. |
| | 4 30 p. m. | 103 | Do. |
| | 4 35 p. m. | 93 | Exudation began. |
| Apr. 15 | 7 a. m. | 27 | Pressure equivalent to 4 atmospheres. |
| | 9 a. m. | 27 | |
| | 12 m. | 24 | |
| | 2 30 p. m. | 45 | |
| | 4 p. m. | 50 | |
| Apr. 16 | 8 a. m. | 57 | Manometer disconnected; leading tube filled with heavy resinous liquid. Emptied, refilled with water and set at 112 mm. |
| | 10 a. m. | 90 | |
| Apr. 17 | 8 a. m. | 82 | Positive or exudation pressure followed renewal, but this gradually lessened until the 19th when absorption began, which continued to lengthen air-column until the 21st, when this phase began to wane and air column was again compressed. |
| | 10 30 a. m. | 82 | |
| | 2 p. m. | 85 | |
| | 3 p. m. | 86 | |
| Apr. 18 | 3 p. m. | 95 | |
| Apr. 19 | 9 a. m. | 106 | |
| Apr. 20 | 9 a. m. | 122 | |
| Apr. 21 | 9 a. m. | 122 | |
| Apr. 22 | 9 a. m. | 107 | |
| Apr. 23 | 9 a. m. | 105 | |
| Apr. 24 | 9 a. m. | 100 | Air-column was maintained in a compressed condition with but little variation for 20 days. At end of this time manometer was taken down. Metal tube and borehole were found to be filled with hardened resin. This removed, and instrument again sealed in place; set at 95. |
| Apr. 25 | 10 30 a. m. | 99 | |
| Apr. 26 | 10 a. m. | 100 | |
| Apr. 27 | 10 a. m. | 100 | |
| Apr. 28 | 9 30 a. m. | 98 | |
| Apr. 29 | 9 15 a. m. | 99 | |
| Apr. 30 | 9 30 a. m. | 99 | |
| May 1 | 9 40 a. m. | 97 | |
| May 13 | 5 p. m. | 95 | |
| May 14 | 8 a. m. | 98 | |
| | 2 p. m. | 98 | |
| May 15 | 8 a. m. | 98 | |
| May 16 | 8 a. m. | 98 | |

The entire cycle of action is coincidental with the exudation of resin into the bores and must be attributed mainly to this cause, the ultimate seat of energy being the osmotically active contents of the living cells which surround the resin ducts. To this may be added the initial hydration and expansion of living cells of the rays and their subsequent contraction by dehydration in a manner which can be best analyzed by

bores made in thick layers of parenchymatous cells. The results of such tests[1] of the action of the thick succulent cortex of the tree cactus, *Carnegiea gigantea,* have been recently described.

## TEST FOR "ROOT-PRESSURE" IN PINE TREES.

The classic form of demonstration of "root-pressure" is by a manometer fitted to the stump of a stem of a small plant. No positive pressures of this kind in the pines seems to have been reported, although slight positive pressures have been detected in branches by various authors. The experiment was repeated as shown in Table 8.

No positive or exudation pressure was shown by this stump, the surface of which was only a few centimeters above the ground. The outflow of resin was slight, and here, as elsewhere in the pines, no action in the roots has been found which would force liquid upward through the wood or the elongated conduits of the protoxylem.

TABLE 7.

| Date. | Time. | Length of air-column. | Date. | Time. | Length of air-column. |
|---|---|---|---|---|---|
| 1925 | | *mm.* | 1925 | | *mm.* |
| June 16 | $8^h30^m$ a. m. | +100 | June 18 | $8^h00^m$ a. m. | +108 |
| | 9 30 a. m. | +104 | | 10 a. m. | +108 |
| | 12 30 p. m. | +106 | | 12 m. | +103 |
| | 2 30 p. m. | + 98 | June 19 | 8 a. m. | + 95 |
| June 17 | 8 a. m. | +107 | | 3 p. m. | + 95 |
| | 9 a. m. | +109 | June 20 | 8 a. m. | + 90 |
| | 11 a. m. | +112 | June 21 | 10 a. m. | + 80 |
| | 3 p. m. | +113 | | | |

## COMPOSITION AND ACTION OF GASES IN TRUNKS OF PINE TREES.

When a bore is driven into the more recently formed wood of the Monterey pine filled with water and quickly connected with a manometer, it is seen that absorption of water and consequent suction takes place during a brief period, generally not exceeding a half hour, when exudation of resin begins and a pressure as high as 4 atmospheres may be developed within the following 30 hours.

If the clogging resin which soon becomes granular is removed, the bore cleaned and the instrument refitted, suction appears and continues indefinitely in the pine. On the other hand, if a bore be made into the center of the trunk and the exudation of resin blocked by screwing a tube deeply into it, suction may be shown at the beginning and also continues indefinitely. It is not always possible to drive bores in such manner as to open only into recently formed water-filled wood, or into wood containing air, but the approximations included in the foregoing experiments serve to demonstrate prevalent conditions.

[1] Proc. Amer. Phil. Soc., 64, 102–130, 1925.

It is generally conceded that the pressure of gases in the central cylinder may be less than atmospheric, and Pappenheim[1] concluded that it may be no more than a fourth of an atmosphere in the conifers. The factors which might affect pressure in the central part of a trunk would be endodermal action in the roots forcing water into the trunk, transpiration in the leaves, setting up tension in the cohesive column in the outer layers, and excessive loss by diffusion of gas from the central cylinder. As to the first factor, it can not be shown that any osmotic action in the root takes place which could force water up through the tracheids of the Monterey pine.

TABLE 8.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925. | | *mm.* | |
| Apr. 15 | 3h30m p. m. | ......... | Small tree cut off 30 cm. from base where stump was 7 mm. thick. No branches remained. Open manometer attached, surfaces being irrigated immediately. |
| | 3 38 p. m. | − 24 | |
| | 4 10 p. m. | − 66 | |
| | 4 30 p. m. | −102 | |
| Apr. 16 | 8 a. m. | − 66 | |
| | 10 a. m. | − 60 | |
| **Date.** | **Time.** | **Length of air-column.** | **Remarks.** |
| 1925. | | | |
| Apr. 17 | 8h m a. m. | − 54 | Refitted to stump which was trimmed. Manometer replaced by one with larger bore and closed end. Air-column 43 mm. |
| | 9 a. m. | − 55 | |
| | 10 30 a. m. | 82 | |
| | 2 p. m. | 65 | Warm and sunny. |
| | 3 p. m. | 75 | |
| Apr. 18 | 3 p. m. | 70 | |
| Apr. 19 | 9 a. m. | 64 | |
| Apr. 20 | 9 a. m. | 43 | Absorption pressure ceased at this point and readings now showed no action for next 20 days. |
| May 14 | 8 a. m. | 43 | Thin section cut from surface and manometer refitted. |
| | 2 p. m. | 48 | |
| May 15 | 8 a. m. | 50 | |
| May 16 | 8 a. m. | 52 | |
| | 3 p. m. | 53 | |
| May 17 | 8 a. m. | 57 | |
| | 3 30 p. m. | 59 | |
| May 18 | 8 a. m. | 61 | |
| May 19 | 2 p. m. | 59 | Rain all night and this day. |
| May 20 | 8 30 a. m. | 59 | |
| May 22 | 8 a. m. | 63 | |
| May 24 | 10 a. m. | 51 | |
| May 25 | 8 a. m. | 51 | |
| | 4 p. m. | 51 | |
| May 26 | 8 a. m. | 51 | |

The pull from the menisci in the walls of the transpiring cells of the leaves sets up tensions under which the new wood contracts, and these layers show increased suction at the same time. This action appears simple, direct, and as expected. When the variations in the central cylinder are considered it is seen that the variations in suction are not

[1] Eine Methode zur Bestimmung der Gasspannung in Splinte der Nädebäume. Bot. Centralb., 19, 1, 33, 65, 97, 161, 1892.

always parallel to those in the outer wood. In fact the anomalies are so striking as to necessitate a thorough reconsideration of the entire matter.

In the first place the conclusion that the gases in the central cylinder are under greatly reduced pressure at all times is open to suspicion. When empty bores of standing trees of the Monterey pine were connected by air-filled tubes and as quickly as possible dipped in water, columns of water no greater than 22 mm. in height were pulled up within a day or two.

It might be objected that the opening of a bore into the wood would allow pressures to be equalized. Communication through the tracheids is by the way of the minute perforations in the membranes closing the pits, and the relief of the pressure could not take place very extensively in the few minutes before the apparatus is sealed into place. The maintenance of such manometers in place for several days should show a reestablishment of the lessened pressure, if it occurs. Repetition of the test, as first performed by Hales two centuries ago with dicotyledons, and illustrated by Pfeffer,[1] gave no decisive results in the pines. Later experiments which may not be described here suggest that the included gases approach atmospheric pressures in the pine most nearly at the beginning of the growing season, but the seasonal course of variation is yet to be determined.

In these and all other tests of the same kind care must be taken to make allowance for the possible absorption of any gases present, especially at high partial pressures.

The composition of the internal gases of Pinus No. 6 was found by analyzing a sample obtained from the bore in which the above air-pressure measurement had been made.

The cavity was first cleaned, then refitted with a brass tube screwed in and securely sealed, after which a gas receiver with column of mercury in a pressure hose was attached. The filling bowl was set to a level to maintain a suction of about 300 mm. Hg., as noted below:

TABLE 9.

| | |
|---|---|
| Oct. 12, 4 p. m. | Gas receiver attached; column set at 300 mm. Hg. |
| Oct. 13, 8 a. m. | About 60 ml. gas and some liquid collected. |
| Oct. 16, 9 a. m. | 200 ml. gas in receiver, which had been drawn out in about 90 hours at pressure of less than 0.5 atmospheres. This was taken for analysis and found to have the following composition by two tests: $CO_2$: 4.24 p. ct.; 4.21 p. ct. O: 15.43 p. ct.; 15.41 p. ct. N: 80.33 p. ct.; 80.38 p. ct. Receiver was again attached at 4 p. m. and air forced out, after which the suction column was set at 500 mm. Hg. |
| Oct. 19, 9 a. m. | About 200 ml. gas had been drawn out in 60 hours, and had invaded a section of rubber tubing not coated with shellac as all other connections had been treated. This would have allowed some exchange with the atmosphere which would have resulted in a lessened proportion of $CO_2$, as is shown in the results of the analysis. The composition of this sample was as below: $CO_2$: 3.85 p. ct.; 3.80 p. ct. $O_2$: 19.99 p. ct.; 15.90 p. ct. N: 76.16 p. ct.; 76.30 p. ct. |

Among the obvious inferences it may be said that, the proportion of N not being widely different from that of the atmosphere, it would

[1] Physiology of Plants. Trans. by A. J. Ewart, 1, 201, 1900.

appear that in the liberation of gases dissolved in the water coming in by the roots some excess of $CO_2$ would result. The periphery of the dead woody cylinder is a region in which progressive maturity of wood and death of ray cells would free more of this gas, while the respiration of elements still alive would be at the expense of oxygen withdrawn from this reservoir, and with some replacement by $CO_2$. The disproportion is much more notable in the walnut (see page 102).

The high partial pressure of $CO_2$—over 150 times as great as in the atmosphere—is conclusive evidence that no direct connection exists between the central cylinder and the atmosphere, and further that the water-filled wood cells, cambium and phloem constitute a complex membrane through which this gas diffuses much less readily than it comes into the central cylinder of the trunk.

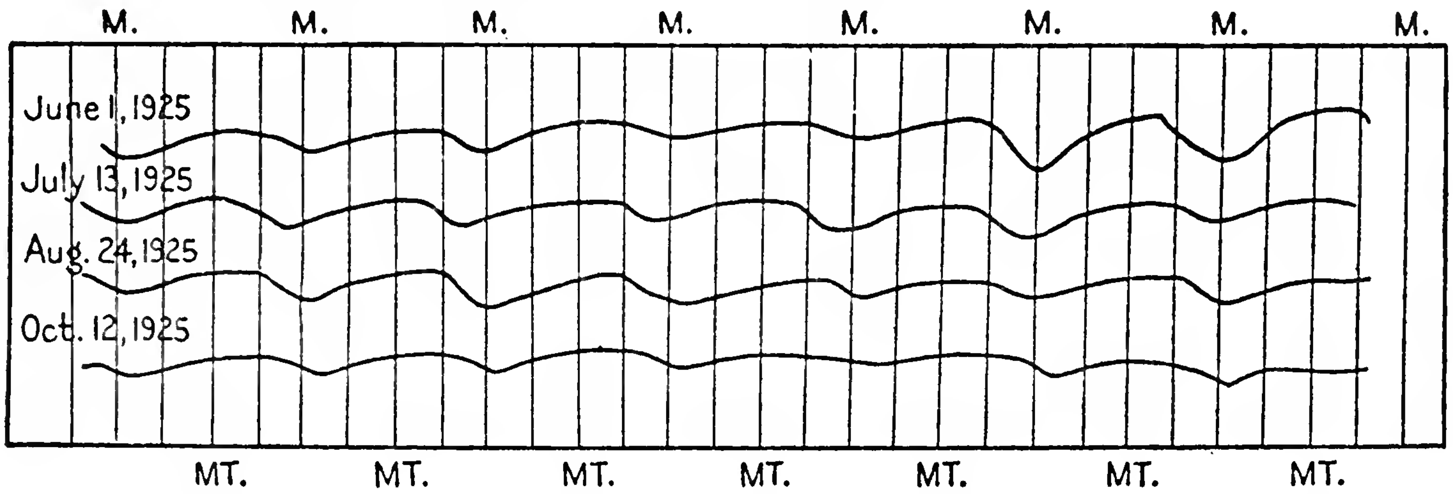



Fig. 10.—Dendrograph record of Monterey pine No. 6 for weeks beginning June 1, July 13, August 24, and October 12, 1925. First week characterized by a high rate of increase in diameter of trunk, with minimum daily contraction of the trunk. Week beginning July 13 was notable for great range of daily variation, during which period variations in suction were very small. Reversible variations were less in week beginning August 24, suction varying from −18 to −30 mm. Hg. Growth was nearing the end. The week beginning October 12 was characterized by reversible variations of slight extent with gradual transition from expansion to contraction. Suction was at a maximum and varied from −78 to −90 mm. Hg. Growth had ceased.

The common practice of bathing cut surfaces of stems, and of filling bores with water in arrangements for measuring pressures, initiates some disturbances not usually taken into account. Theoretically, air would be drawn into the ends of the wood in which the meshwork column of water under tension exists, when this is cut into. Water applied to the surface would lessen the entrance of air or prevent it entirely. At the same time application of water to the surface of older wood in which a pressure less than atmospheric prevails would result in some liquid being drawn into the wood, thus setting up conditions not present in the intact trunk. Still further, water would enter tubes and conduits or the tracheids by capillarity to an extent determined chiefly by the size of the openings. The attachment of a manometer to a stump or to a bore of a pine tree would entail a capillary movement of water into the wood in such manner that suction not previously existent would be registered. Such action would be heightened by the solution of some of the gases present in the entrant liquid.

## SUCTION AND PRESSURE IN RADIAL AND TANGENTIAL BORES—MONTEREY PINE.

Preliminary to the extensive observations recorded in the preceding pages, closed manometers, of the type illustrated in figure 2, were used in making tests between pressures in tangential and radial bores driven in a small standing pine tree, which had an attenuated trunk with thin layers and a diameter of 15 cm. a meter from the base.

The first pair was installed May 15, 1925, and showed readings of the manometer connected radially of an increase in the air-column of a closed manometer from 88 to 91 mm., a compression to 86 mm. on the next day, while on the third and fourth days the column was drawn out to 92 to 95 mm. Absorption was in evidence during most of the period in question. The manometer connected with a tangential bore-hole showed absorption which extended the air-column from 80 to 96 mm. within 3 hours, a compression to 62 mm. on the following day, then extension for 2 days. Both extension and compression were more marked in the tangential than in the radial bore-hole. The instruments reset in a new pair of holes on May 21 showed only absorption of water or suction.

The instruments were now refitted to new holes which extended through the trunk, which were closed at the farther end by screw plugs securely sealed. The radial cavity showed an exudation pressure which compressed an air-column from 112 mm. to 107 mm. 7 hours later; absorption followed, extending the air-column from 112 to 120 mm. The tangential cavity showed absorption initially, by which an air-column of 93 mm. was extended to 110 mm. in 3 hours, then exudation by which it was compressed to 65 = 1.4 atm. on the following day.

The tree was now cut down, a basal section sawed off, and the newly exposed basal surface of the trunk coated with a layer of Canada balsam in cedar oil. A hole 8 mm. in diameter was bored longitudinally, centered in the 3 outer layers to a length of 10 cm., into which a brass tube was screwed, sealed and connected with a manometer with closed end. The 4 outer layers had a total thickness of about 16 mm., and the cavity did not cut the outermost. A similar fitting was made in the center of the trunk.

Both connecting tubes were filled with a fuchsin solution. The outer layers gave immediate and rapid absorption when set up at 9.15 a. m., but air was soon drawn out of the wood. When reset at 9.25 a. m. the column of air in the closed end of the manometer was extended from 102 to 112 mm. in 5 minutes. At the end of 15 minutes the column was extended to 123 mm., at which point it was nearly stationary at the end of 30 minutes.

The column of air of the instrument connected with the center of the trunk, 96 mm. in length originally, was extended slowly, no air was

drawn out of the wood, and at the end of 15 minutes the column was 101, where it remained nearly stationary.

At 10.30 a. m., the column connected with the center of the trunk was stationary as above. The column connected with the outer layer was extended to 116 mm. and some air had been drawn into the system. When this was removed and the column set at 0, immediate extension of the column indicated a continuing absorption.

At 3.30 p. m. the center column was unchanged. It was reset to 96. Some air had been drawn out of the outer wood into the leading tube of the manometer attached, the pressure column being extended from 102 to 110 mm. The instrument being cleared and reset to 0, the pressure column was extended from 102 to 118 mm. in 10 minutes. The column in the instrument attached to the center of the trunk was extended from 96 to 103 mm. in the same time.

Suction or absorption in the outer layers of wood was seen to draw air from the wood at 0.2 atmosphere. Suction in the central part of the trunk did not exceed 0.05 atmosphere, and no air was drawn out of the wood. The outer column was again extended to 118 and the center one to 108 mm. in 15 minutes.

On the following morning, and 24 hours after the tests had been begun, the column of the centrally connected manometer had been extended from 96 to 105 mm., and no air had been drawn in. Gas had been drawn into the leading tube of the manometer connected with the cavity in the outer wood to an amount occupying the greater part of the space from which about 10 ml. water had been absorbed. This gas was released (7 a. m.), and the column set to 0. Immediate absorption caused the extension of the air column from 102 to 107 mm. in 10 minutes. An hour later (8.20 a. m.) the air column was 115 mm. in length, and a large bubble (2 ml.) had been drawn in. This was released and the column set to 0. The column connected with the center had been extended to 110, in this interval. Immediate absorption showed in the outer layer, so that the column was extended from 102 to 110 mm. in 10 minutes. The pressure stood at this point and was equivalent to nearly 0.08 atmosphere, and at the end of a half-hour a bubble of gas had been drawn into the leading tube. The column was reset to 0 at 8.45 a. m. A repetition was noted by 10.10 a. m., at which time similar action was noted in a manometer fitted to the opposite side of the trunk. Similar observation was made at 11 a. m., at which time the central bore had drawn the air-column in the manometer from 96 to 112 mm. with no air in the system. A day later the centrally connected column extended from 96 to 118 mm. = 0.23 atmosphere. The exudation of resin into bores in the standing tree was sufficient to cause some positive or exudation pressure in both radially and tangentially driven cavities in the early part of the tests; later suction pressures appeared.

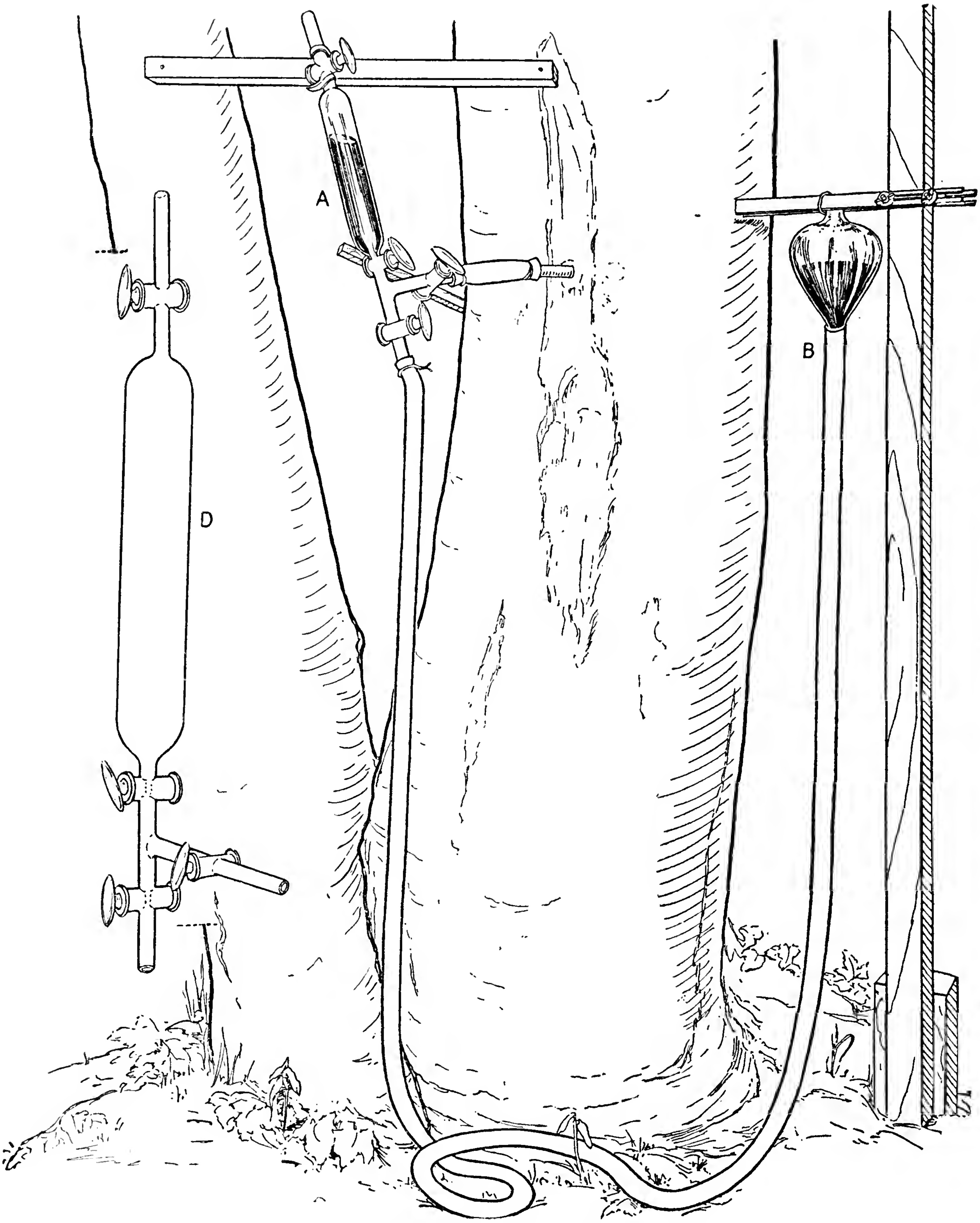



FIG. 11.—Gas receiver D. A, in position, attached by section of rubber pressure tubing to metal tube screwed into radial bore of oak tree. Column of mercury from bulb, B, is extended through long section of pressure tubing to fill receiver and tubes completely. Gases originally present are forced out of upper end of receiver, after which bulb, B, is placed at level which will give suction desired. All rubber tubing into which gas may be drawn is heavily coated with shellac.

The most interesting phase of these results, however, is that of the suction exerted by the different layers after the trunk had been cut off. Tubes screwed into the sealed base of the trunk, one thus connecting longitudinally with the water-column in the outer layers, and the other with the central old wood, gave opportunities for comparing the suction in the two regions. It was seen that water was taken in at a lower rate and conducted to a much smaller distance in the inner wood than in the recently formed outer layers. It was to be expected that the pull from the leaves would cause greater suction in the outer layers. The continued extraction of gas from these layers at 0.2 atmosphere proved the presence of some air-filled tracheids in the 4 outer layers.

## EXTENDED TESTS OF STUMP AND BORES OF A SINGLE PINE TREE.

The foregoing series of measurements was made on several trees. It was important to carry out some tests with manometers connected with different parts or combinations of the hydrostatic system of a single tree and to follow the resultant changes in suction or pressure through an extended period. Instruments were therefore attached to a small tree (No. XV), 10 meters in height and 20 cm. in diameter at the base as follows (fig. 12B): Tangential bore 80 cm. from base of tree, 4 cm. in depth, into which a tube of the type shown in figure 8 C was screwed about 2 cm.; A, radial bore driven 12 cm. through the center of the trunk 35 cm. from its base into which a tube of the type of tube of figure 8 B was screwed 3 cm.; D, radial bore 80 cm. from the base, 3 cm. in depth into which a tube of the type figure 8 C was driven 2 cm.; and C, a section of pressure tubing was clamped to the stump of a branch 110 cm. from the base of the trunk. The tangential bore B probably connected, to some extent, with the central cylinder of air-filled wood; D was intended to penetrate its outer part; and the deep bore A undoubtedly gave free and full connection with it. C was connected with the air-filled wood through the protoxylem and central wood and with the outer solution carrying recently formed layers. It is probable that the cortex and bark were so compressed as to cut off direct communication with the water in the leading tube of the manometer. Closed manometers were first used, to be replaced later by the type shown in figure 11. Observations made in the August-November period are given in Table 10.

TABLE 10.

| Date. | Time. | Tangential. | Radial. Deep. | Radial. Shallow. | Stump of branch. | Remarks. |
|---|---|---|---|---|---|---|
| | | (Figures indicate suction in mm. Hg.) | | | | |
| 1925 | | | | | *Water absorbed:* | |
| Aug. 15 | 3h00m p. m. | 115 | 115 | ........ | .................. | Water was absorbed in such quantity by the stub of the branch that the instrument was opened to allow calibration of amount taken in. Much air was drawn out from the shallow radial bore. |
| | 4 p. m. | 134 | 115 | ........ | .................. | |
| | 5 45 p. m. | 120 | 110 | ........ | .................. | |
| Aug. 16 | 8 45 a. m. | ...... | ...... | 108 = 0 | .................. | |
| | 9 a. m. | 98 | 80 | 130 | .................. | |
| | 10 40 a. m. | 96 | 78 | 116 | .................. | |
| | 4 p. m. | 98 | 80 | 125 | .................. | |
| Aug. 17 | 7 30 a. m. | 100 | 85 | ........ | .................. | |
| | 11 30 a. m. | 100 | 87 | 110 | .................. | |
| | 4 p. m. | 103 | 87 | 115 | .................. | |
| Aug. 18 | 7 30 a. m. | 104 | 93 | 115 | .................. | |
| | 11 a. m. | 105 | 95 | 114 | .................. | |
| | 4 p. m. | 105 | 94 | 116 | .................. | |
| Aug. 19 | 7 a. m. | 106 | 97 | 117 | .................. | |
| | 11 45 a. m. | 105 | 97 | 115 | 4 ml. in 5 hrs..... | |
| | 4 15 p. m. | 107 | 97 | 117 | 13 ml. in 4.5 hrs... | |
| Aug. 20 | 7 30 a. m. | 108 | 107 | 114 | 24 ml. in 11 hours. | |
| | 11 30 a. m. | 109 | 108 | 114 | 7 ml. in 4 hrs..... | |
| Aug. 21 | 3 30 p. m. | 108 | 100 | 113 | 55 ml. in 28 hrs.... | |
| Aug. 22 | 8 a. m. | 110 | 101 | 114 | 18 ml. in 16.5 hrs... | |
| | 11 30 a. m. | 108 | 101 | 113 | 5 ml. in 3.5 hrs..... | |
| | | 107[1] | 113[1] | 107 | | |
| | 5 p. m. | 113 | 116 | 107 | Filled with water. | Cleaned and reset at 122. |
| | (Figures indicate length of air column in closed end of manometer.) | | | | | |
| Aug. 23 | 8 a. m. | 107 | 122 | 105 | 14 ml. in 15 hrs... | |
| | 11 15 a. m. | 108 | 122 | 110 | 3 ml. in 3 hrs...... | |
| | 4 30 p. m. | 110 | 122 | 117 | 7 ml. in 4.75 hrs... | |
| Aug. 24 | 7 30 a. m. | 112 | 125 | 124 | 8 ml. in 15 hrs.... | |
| | 11 30 a. m. | 109 | 127 | 123 | 7 ml. in 8.5 hrs.... | |
| | 4 p. m. | 109 | 127 | 123 | .................. | |
| Aug. 25 | 7 30 a. m. | 113 | 115 | 127 | .................. | |
| | 11 30 a. m. | 111 | 114 | 127 | 2.5 ml. in 4 hrs.... | |
| | 4 p. m. | 113 | 130 | 135 | 2 ml. in.......... | |
| Aug. 26 | 8 a. m. | 115 | 130 | 139 | 3 ml. in 16 hrs..... | |
| | 11 30 a. m. | 113 | 131 | 136 | 0.5 ml. in 3.5 hrs.. | |
| | 7 15 p. m. | 116 | 131 | 139 | 1.5 ml. in 7.75 hrs. | |
| | | | | | *Suction in mm. Hg.* | |
| Aug. 27 | 6 a. m. | 116 | 114 | 138 | 137.............. | See record of No. 28 for environmental conditions. |
| | 7 a. m. | 116 | 130 | 138 | 137.............. | |
| | 8 a. m. | 115 | 130 | 137 | 136.............. | |
| | 9 a. m. | 115 | 131 | 139 | 138.............. | |
| | 10 a. m. | 114 | 132 | 137 | 136.............. | |
| | 11 a. m. | 114 | 131 | 136 | 137.............. | |
| | 12 m. | 114 | 130 | 136 | 139.............. | |
| | 2 p. m. | 115 | 130 | 137 | 142.............. | |
| | 3 p. m. | 115 | 131 | 137 | 143.............. | |
| | 4 p. m. | 115 | 130 | 137 | .................. | Reset with open manometers as shown in fig. 11. |
| | | Figures in mm. Hg. | | | *Absorbed.* | |
| | 5 p. m. | −2 | ...... | − 6 | −8. 350 ml. by stump in 6 days. | |
| | 8 p. m. | −5 | −0 | −13 | −20............ | |
| | 11 p. m. | −8 | −0 | −24 | −42............ | |
| Aug. 28 | 3 a. m. | −8 | −1 | −32 | −70............ | |
| | 4 a. m. | −9 | −2 | −34 | −80............ | |

Table 10—*Continued.*

| Date. | Time. | | Tangential. | Radial. | | Stump. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | | | Deep. | Shallow. | | |
| | | | (Figures indicate suction in mm. Hg.) | | | | |
| 1925 | | | | | | | |
| Aug. 28 | $6^h00^m$ | a. m. | − 9 | − 0 | − 36 | − 85 | |
| | 8 | a. m. | − 9 | − 0 | − 36 | − 89 | |
| | 9 | a. m. | − 8 | − 1 | − 36 | − 90 | |
| | 10 | a. m. | − 9 | − 1 | − 35 | − 86 | |
| | 11 | a. m. | − 8 | − 1 | − 36 | − 84 | |
| | 2 | p. m. | − 9 | − 1 | − 39 | − 84 | |
| | 4 | p. m. | − 10 | Reset. | − 43 | − 96 | |
| | 7 | p. m. | − 12 | − 12 | − 50 | − 15 | |
| | 9 | p. m. | − 15 | − 19 | − 54 | − 13 | |
| Aug. 29 | 3 | a. m. | − 15 | − 30 | − 66 | − 12 | |
| | 4 | a. m. | − 15 | − 33 | − 64 | − 14 | |
| | 6 | a. m. | − 15 | − 34 | − 64 | − 12 | |
| | 8 | a. m. | − 16 | − 35 | − 66 | − 12 | |
| Aug. 30 | 9 | a. m. | − 18 | − 66 | − 78 | − 13 | Air released from stump and reset to 0. |
| Aug. 31 | 9 | a. m. | − 74 | − 86 | − 83 | − 72 | |
| | 4 | p. m. | − 24 | − 81 | − 86 | − 70 | |
| Sept. 1 | 7 | a. m. | − 32 | − 92 | − 95 | − 13 | |
| | 12 | m. | − 38 | − 96 | − 90 | − 5 | |
| | 7 | p. m. | − 42 | −108 | −103 | − 80 | |
| Sept. 2 | 7 | a. m. | − 57 | −102 | − 90 | − 73 | |
| | 11 | a. m. | − 42 | −109 | −101 | − 41 | |
| Sept. 5 | 11 | a. m. | − 56 | −122 | −123 | − 72 | |
| | 6 30 | p. m. | − 56 | −126 | −134 | −108 | |
| Sept. 6 | 8 30 | a. m. | − 62 | −129 | −138 | −139 | |
| | 6 | p. m. | − 62 | −116 | −129 | −116 | Air released from stump; reset at −116. |
| Sept. 7 | 7 30 | a. m. | − 68 | −135 | −135 | −134 | |
| | 11 15 | a. m. | − 66 | −134 | −135 | − 81 | |
| | 4 30 | p. m. | − 67 | −106 | −108 | −138 | |
| Sept. 8 | 7 30 | a. m. | − 72 | −146 | −134 | −130 | |
| | 11 30 | a. m. | − 69 | −140 | −120 | − 84 | Reset at 84 after release of air. |
| | 4 | p. m. | − 72 | −132 | − 91 | −130 | |
| Sept. 9 | 8 | a. m. | − 76 | −135 | −135 | −122 | |
| | 11 30 | a. m. | − 73 | −132 | −115 | − 98 | |
| Sept. 10 | 7 30 | a. m. | − 67 | −141 | −129 | −129 | |
| Sept. 13 | 8 | a. m. | − 90 | −120 | −102 | −120 | Air released; reset at −120. |
| | 6 | p. m. | − 93 | − 0 | − 88 | −122 | Refitted. |
| Sept. 14 | 7 15 | a. m. | − 96 | − 18 | −100 | −130 | |
| | 11 30 | a. m. | − 92 | − 3 | − 90 | − 81 | |
| | 4 | p. m. | − 93 | − 3 | − 92 | −108 | |
| Sept. 15 | 7 15 | a. m. | − 98 | − 18 | −102 | −120 | |
| | 3 30 | p. m. | − 93 | − 0 | − 96 | − 92 | Reset at −84 after release of air. |
| Sept. 16 | 7 30 | a. m. | −100 | − 14 | −111 | −116 | |
| Sept. 18 | 7 | a. m. | −108 | − 26 | −141 | −108 | |
| Sept. 20 | 9 | a. m. | −110 | − 22 | −141 | − 96 | Air released; reset at −96. |
| Sept. 21 | 7 30 | a. m. | −102 | − 28 | −148 | − 78 | |
| | 11 30 | a. m. | − 95 | − 10 | −136 | − 20 | |
| | 4 | p. m. | − 97 | − 12 | −151 | − 66 | |
| Sept. 22 | 7 30 | a. m. | −104 | − 26 | −146 | − 57 | |
| | 11 30 | a. m. | −100 | − 13 | −139 | − 24 | |
| | 5 30 | p. m. | −102 | − 15 | −136 | − 56 | |
| Sept. 23 | 8 | a. m. | −108 | − 29 | −148 | − 72 | |
| | 12 | m. | −106 | − 22 | −152 | − 42 | |
| | 4 | p. m. | −107 | − 16 | −146 | − 50 | |
| Sept. 24 | 7 15 | a. m. | −111 | − 30 | −146 | − 70 | |
| | 11 30 | a. m. | −111 | − 21 | −125 | − 42 | |
| | 4 | p. m. | −111 | − 20 | −152 | − 50 | |
| Sept. 25 | 8 | a. m. | −115 | − 29 | −144 | − 60 | |
| | 5 | p. m. | −114 | − 18 | −153 | − 51 | |

TABLE 10—*Continued.*

| Date. | Time. | Tangential. | Radial. Deep. | Radial. Shallow. | Stump. | Remarks. |
|---|---|---|---|---|---|---|
| | | (Figures indicate suction in mm. Hg.) | | | | |
| 1925 | | | | | | |
| Sept. 26 | $7^h15^m$ a. m. | −120 | − 33 | −146 | − 68 | |
| | 11 45 a. m. | −114 | − 18 | −130 | − 21 | |
| | 4 p. m. | − 97 | − 17 | −135 | − 45 | |
| Sept. 28 | 7 30 a. m. | −122 | − 27 | −146 | − 68 | |
| Sept. 29 | 9 45 a. m. | −126 | − 36 | −151 | − 84 | |
| Sept. 30 | 4 p. m. | −106 | − 17 | −132 | − 65 | Air released; reset at 0. |
| Oct. 4 | 9 a. m. | −124 | − 34 | − 60 | − 60 | |
| | 4 p. m. | −135 | − 24 | − 65 | − 57 | |
| Oct. 5 | 7 30 a. m. | −130 | − 36 | − 76 | − 60 | |
| | 2 30 p. m. | −126 | − 24 | − 71 | − 42 | |
| Oct. 6 | 7 30 a. m. | −134 | − 40 | − 87 | − 84 | |
| | 5 p. m. | −132 | − 26 | − 83 | − 63 | |
| Oct. 7 | 7 45 a. m. | −136 | − 44 | − 96 | − 91 | |
| | 12 m. | −128 | − 26 | − 84 | − 55 | |
| | 3 15 p. m. | −132 | − 24 | − 88 | − 63 | |
| | 6 30 p. m. | −135 | − 30 | − 92 | − 82 | |
| Oct. 8 | 7 30 a. m. | −140 | − 43 | −107 | −100 | |
| | 4 p. m. | −134 | − 25 | − 96 | − 75 | |
| Oct. 9 | 7 30 a. m. | −140 | − 37 | −108 | − 96 | |
| | 3 30 p. m. | −139 | − 32 | −105 | − 81 | |
| Oct. 10 | 8 a. m. | −143 | − 31 | −111 | − 94 | |
| | 12 m. | −135 | − 27 | −108 | − 80 | |
| | 4 p. m. | −141 | − 24 | −113 | − 84 | |
| Oct. 11 | 8 a. m. | −144 | − 30 | −120 | − 96 | |
| Oct. 12 | 8 a. m. | −153 | − 44 | −130 | −108 | |
| | 4 p. m. | −150 | − 27 | −126 | − 86 | |
| Oct. 13 | 8 a. m. | −156 | − 48 | −137 | −114 | |
| | 2 p. m. | −150 | − 34 | −126 | − 84 | |
| Oct. 14 | 8 a. m. | −157 | − 48 | −152 | −110 | |
| Oct. 16 | 9 a. m. | −162 | − 42 | −144 | −106 | |
| | 4 p. m. | −139 | − 36 | −139 | − 98 | |
| Oct. 17 | 8 a. m. | −152 | − 41 | −146 | −107 | |
| Oct. 18 | 8 a. m. | −166 | − 51 | −144 | −114 | |
| Oct. 19 | 8 a. m. | −130 | − 49 | −144 | −115 | |
| | 4 p. m. | −140 | − 29 | −130 | − 80 | |
| Oct. 20 | 7 30 a. m. | −168 | − 43 | −146 | −114 | |
| | 2 p. m. | −162 | − 29 | −142 | − 83 | |
| Oct. 21 | 8 a. m. | −168 | − 42 | −146 | −111 | |
| Oct. 22 | 4 p. m. | −168 | − 36 | −138 | − 99 | |
| Oct. 23 | 7 a. m. | −134 | − 42 | −136 | −120 | |
| | 11 a. m. | −170 | − 36 | Taken out | −102 | |
| Oct. 24 | 7 a. m. | −178 | − 52 | ....... | −127 | |
| | 12 m. | −172 | − 39 | ....... | − 95 | |
| | 7 p. m. | −174 | − 38 | ....... | −104 | |
| Oct. 25 | 8 a. m. | −176 | − 48 | ....... | −110 | |
| Oct. 26 | 7 30 a. m. | −174 | − 44 | ....... | −116 | |
| Oct. 27 | 8 a. m. | −179 | − 51 | ....... | −126 | Manometer replaced by gas receiver and suction column. |
| | 4 p. m. | −136 | − 38 | ....... | −111 | |
| Oct. 28 | 7 30 a. m. | −183 | − 54 | ....... | −123 | |
| | 4 p. m. | −180 | − 45 | ....... | −108 | |
| Oct. 29 | 2 p. m. | −180 | − 43 | ....... | −102 | |
| Oct. 30 | 7 30 a. m. | −186 | − 54 | ....... | −122 | |
| Oct. 31 | 8 a. m. | −186 | − 49 | ....... | −114 | Overcast. |
| Nov. 1 | 10 30 a. m. | −182 | − 40 | ....... | −108 | Do. |
| Nov. 2 | 8 a. m. | −179 | − 54 | ....... | −111 | Showers. |
| Nov. 3 | 9 a. m. | −132 | − 64 | ....... | −136 | Clearing. |
| Nov. 4 | 8 a. m. | −130 | − 65 | ....... | −122 | Do. |
| | 11 a. m. | −125 | − 62 | ....... | −125 | Clear. |
| | 4 p. m. | −122 | − 59 | ....... | −122 | Do. |

TABLE 10—*Continued.*

| Date. | Time. | | Tangential. | Radial. | | Stump. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | | | Deep. | Shallow. | | |
| | | | (Figures indicate suction in mm. Hg.) | | | | |
| 1925 | | | | | | | |
| Nov. 5 | $8^h$ $^m$ | a. m. | −134 | − 80 | ....... | −123 | Clear. |
| | 4 | p. m. | −138 | − 56 | ....... | −102 | Do. |
| Nov. 6 | 8 | a. m. | −138 | − 81 | ....... | −138 | Do. |
| | 3 | p. m. | −129 | − 67 | ....... | − 96 | Do. |
| Nov. 7 | 8 | a. m. | −138 | − 81 | ....... | −124 | Do. |
| Nov. 8 | 10 | a. m. | −134 | − 68 | ....... | − 98 | Do. |
| Nov. 9 | 8 | a. m. | −144 | − 78 | ....... | −135 | Do. |
| | 3 | p. m. | −137 | − 61 | ....... | − 92 | Cloudy. |
| Nov. 10 | 4 | p. m. | −138 | − 60 | ....... | − 96 | Do. |
| Nov. 11 | 7 30 | a. m. | −144 | − 60 | ....... | −101 | Raining. |
| | 4 | p. m. | −142 | − 57 | ....... | − 96 | Do. |
| Nov. 12 | 8 | a. m. | −143 | − 68 | ....... | −118 | Cloudy. |
| | 4 | p. m. | −144 | − 60 | ....... | − 98 | Raining. |
| Nov. 13 | 7 30 | a. m. | −162 | − 78 | ....... | −127 | Clear. |
| Nov. 14 | 7 | a. m. | −157 | − 84 | ....... | −140 | Do. |
| | 4 | p. m. | −147 | − 68 | ....... | − 96 | Do. |
| Nov. 15 | 8 | a. m. | −156 | − 80 | ....... | −122 | Do. |
| | 1 30 | p. m. | −146 | − 66 | ....... | − 90 | Clear; air released; reset same. |
| | 4 | p. m. | −141 | − 66 | ....... | −102 | Cloudy. |
| Nov. 16 | 8 | a. m. | −154 | − 65 | ....... | −102 | Drizzle. |
| Nov. 17 | 7 30 | a. m. | −158 | − 66 | ....... | −124 | Clear. |
| Nov. 18 | 7 30 | a. m. | −150 | − 80 | ....... | −121 | Do. |
| | 11 30 | a. m. | −151 | − 66 | ....... | − 90 | Do. |
| | 2 | p. m. | −151 | − 64 | ....... | − 89 | Do. |
| | 7 | p. m. | −156 | − 67 | ....... | −108 | Do. |
| Nov. 19 | 7 30 | a. m. | −160 | − 75 | ....... | −114 | Do. |
| Nov. 20 | 8 | a. m. | −159 | − 74 | ....... | −113 | Do. |
| | 11 30 | a. m. | −150 | − 60 | ....... | − 78 | Do. |
| | 2 | p. m. | −149 | − 60 | ....... | − 78 | Do. |
| | 4 30 | p. m. | −153 | − 57 | ....... | − 90 | Do. |
| Nov. 21 | 8 | a. m. | −160 | − 74 | ....... | −139 | Overcast. |
| | 12 | m. | −152 | − 62 | ....... | − 81 | Slightly overcast. |
| | 4 | p. m. | −150 | − 55 | ....... | − 80 | Overcast. |
| Nov. 22 | 8 | a. m. | −158 | − 75 | ....... | −120 | Do. |
| Nov. 23 | 7 30 | a. m. | −157 | − 60 | ....... | −102 | Do. |
| Nov. 24 | 7 30 | a. m. | −157 | − 60 | ....... | −107 | Do. |
| | 2 | p. m. | −157 | − 56 | ....... | − 96 | Clear. |
| Nov. 25 | 7 | a. m. | −168 | − 78 | ....... | −132 | Do. |
| | 2 | p. m. | −154 | − 66 | ....... | −101 | Hazy. |
| Nov. 26 | 12 | m. | −166 | − 74 | ....... | −102 | Do. |
| Nov. 27 | 8 | a. m. | −174 | − 80 | ....... | −126 | Clear. |
| Nov. 28 | 8 | a. m. | −175 | − 89 | ....... | −126 | Do. |

Some positive or exudation pressure was exhibited by all of the bores, presumably due to exudation of resinous material from the canals, with some participation by the contraction of living cells of the rays and xylem. The pressure thus set up in the tangential bore compressed an air-column from 115 to 108 mm., indicative of a pressure of 1.16 atmospheres. A pressure of 1.6 atmospheres was found in the deep radial bore, while the shallow radial bore showed so little action in the initial tests as to suggest that the fittings were defective.

The water in the three bores doubtless injected the wood-cells for some distance in a longitudinal direction and connected to some extent with the water-column in the outer layers. The irregular increase of suction in consequence of this capillary movement of water away from the bore extended over such long periods that the daily variation was difficult to determine. Some slight movement may take place through the walls but capillary action would be through the minute perforations of the membranes of the pits, and would be much slower than in the vessels and large conduits of the walnut and oak.

A week after the bores had been made it was seen that variations in suction in the tangential and deep radial bores showed an increase throughout the day, while a diminution took place in the shallow bore. Then on September 8, suction was high morning and evening with a minimum at mid-day, while a progressive decrease took place throughout the day in the shallow radial bore. Finally on September 21, after various adjustments that made comparisons of some value, all showed high suction in the morning, a minimum at mid-day, and an increase by 4 p. m. Trunk temperatures of a walnut tree near by were 13°, 25° and 20° C. A similar variation was seen on the following day. A lessened suction in the mid-day period of high temperature could not be attributed to increased tension in the water-column, which would have the reverse effect, but must have been due to expansion of the gases in the old wood as is discussed at length in connection with the observations on the walnut. Movements of both air and water encounter much greater resistance in the stem of the pine than in the dicotyledonous trees, and the variations are not so clear-cut or so readily correlated with external conditions.

The records show that on many days suction lessened continuously throughout the day. The fact, however, that it was greatest at dawn at the time of lowest temperature indicates the dominance of changes in volume in determining the variations.

The measurements of variations in suction of the stump of the branch (fig. 12 C) show much more pronounced variations. The section to which the manometer was clamped was 28 cm. in length and about 27 mm. in diameter, and it may be taken to communicate with at least 10 layers of the older wood. Much water was drawn into the disintegrating medulla and wood and consequently a large amount of air came out. The surface exposed by the cut was relatively so small that not enough material was exuded to set up a positive pressure.

Daily records were made by September 1, of −13, −5 and −80; September 8, 130, 84 and 130; September 14, 130, 81 and 108; September 21, 78, 20 and 66. These were ample evidence of the effect of the expansion and contraction of gases in the system, as may be seen by reference to trunk temperatures of *Juglans*. Weather conditions,

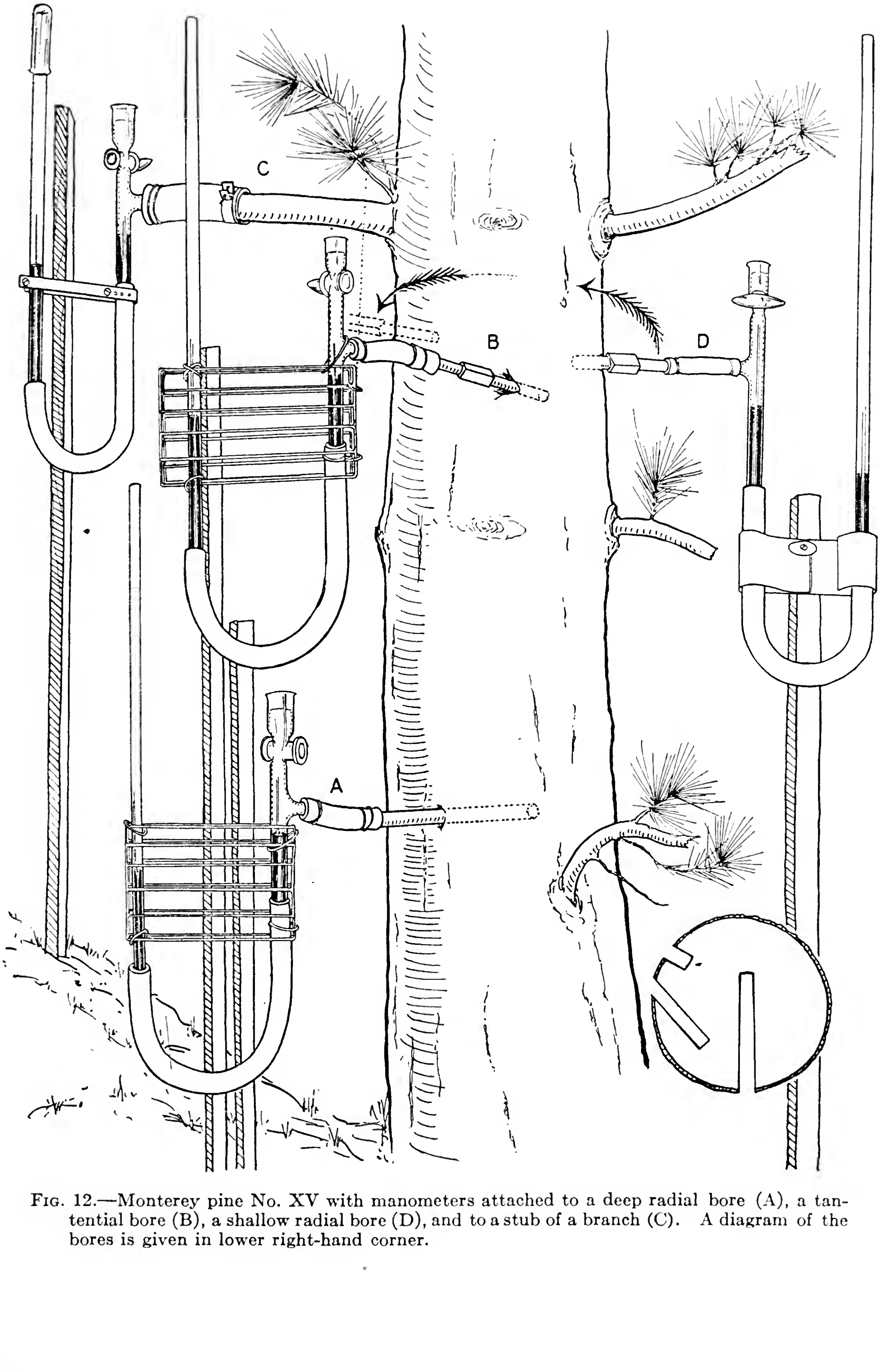



FIG. 12.—Monterey pine No. XV with manometers attached to a deep radial bore (A), a tantential bore (B), a shallow radial bore (D), and to a stub of a branch (C). A diagram of the bores is given in lower right-hand corner.

other than those of clear days and nights, induce variations not so easily analyzed.

Maximum suction of −116 to −158 mm. Hg. was observed in the tangential bore; −43 to −146 in the deep radial bore; −115 to −132 in the shallow radial bore; and −100 to −143 mm. in the stump of the branch. The greatest daily variation characterized the stump of the branch which communicated most freely with the gases of the interior, the suction sometimes being as much as 59 mm. Hg. less at mid-day than in the morning, while variation in suction from the bases would be not more than a third this range.

## EFFECTS OF ARTIFICIAL SUCTION APPLIED TO ROOTS AND STEMS.

The conception of the hydrostatic system of the pine as described in the opening section of this paper is one which includes the presence of a central body of gases enclosed in wood, communicating by very minute openings from tracheid to tracheid and by the tracheæ when present. Exchange with the atmosphere is reduced to a minimum, and actually takes place only across the membranes of the absorbing parts of the roots and through the walls of transpiring leaves.

The presence of such a body of gas in the central wood may be considered as offering some of the features of the air-chamber in a pump. It is obvious that when a stem or branch is cut across and its entire cross-section connected with a pump or gage, that the unusual mechanical conditions created can not be easily analyzed.

Furthermore, when comparisons are made between the effects of suction applied at one end and pressure applied at the other, it will be found, for example, that the effects of an exhaust of 0.5 atmosphere are not identical with those resulting from the application of equivalent pressure at the other. No detailed examination of this matter is to be reported here, but mention was made of such differing results in a previous publication, which concerned the path of introduced solutions chiefly.[1] It seems clear that most of the current generalizations on resistance of sap flow through stems and transpiration pull must be revised in accordance with the conception of the hydrostatic system as presented in this paper. This is well illustrated by the following experiments in absorption and conduction of sap by prevalent methods, which were carried out in 1925.

*June 14.* A branch a meter long with leader, terminal whorl of 3 and a lower whorl of 4 branches, cut from crown of pine was set in upright position and a manometer filled with water was clamped to base. The entrance of water into the stem was accompanied by extension of air into leading tubes,

[1] MacDougal, D. T. Comparative conduction under suction or transpirational pull, and under pressure basally applied. Pp. 21–27 in "Reversible variations in volume, pressure, and movements of sap in trees," Publ. 365, Carnegie Inst. Wash., 1925.

and the amount of air coming out was increased when mercury was introduced into the U tube (instrument as in fig. 3). Air was continually pulled out of the stem at such a rate that suction no higher than 10 mm. Hg. was registered.

During the ensuing 48 hours, water was taken up at a rate of 25 to 40 ml. in 24 hours. The preparation stood in a skylighted and warmed room.

*June 16. At 8$^{h}$30$^{m}$ a. m.* the manometer was replaced by a vertical tube filled with water and standing in a dish of mercury. Absorption by the stem through its base raised a column of Hg. 80 meters in the first 15 minutes, and no air was drawn out of the stem. The mercury rose in a tube 2 mm. in diameter, and hence the amount of water absorbed was about 0.5 ml.

At 9 a. m. the column had risen to 90 mm., or an additional 10 mm. in 15 minutes. At 9$^{h}$15$^{m}$ the column had fallen to 15 mm., and drawn some air from the stem. When this air was released and the water-column again brought to the base of the stem in repeated tests, air would be drawn from the stem at lesser suction values. Such free communication was probably through the cortex to the outside air, while at the same time the gases in the medulla and protoxylem would expand under suction and some would escape into the tube.

A small pine tree, 3 meters in height, was cut, the leader was removed, and the end connected by a clamped rubber hose with a pump, while the base was set in a vessel containing fuchsin 1-1000 in water. During the next two days the pressure was repeatedly raised by suction to 750 mm. Hg. When the pump was cut off, the column would fall about 40 mm. in 15 minutes, and the resistance did not change much in the 2 days the experiment was continued. The tree was dissected 50 hours after the experiment had been begun. The dye had ascended to the uppermost of the four whorls of branches, a distance of 1.5 meters, which would imply an average rate of 3 cm. per hour. In this, as in previous experiments in which the pump was connected with the entire stem, the rate of such conduction of dye did not seem to be greatly affected, although some accelerations have been found. It is plainly evident that the application of suction to the entire end of the stem would produce results not directly comparable to the action of transpiring surfaces in leaves connected directly and only with the continuous water-column in the separate layers of newer wood, in which radial communication is very restricted. This would also apply to roots, as shown by the following experiment.

*July 7.* Section of root of Monterey pine, a meter in length, 15 mm. in diameter at the larger end and 10 mm. at the smaller, was connected at the larger end with the air pump, and the smaller was stepped in a vessel containing a fuchsin solution. After operation of the pump maintaining a column of Hg. 740 to 750 mm. for about 8 hours with intervals, the dye had been pulled to a length of only about 85 cm. The color was not seen in the central part, but stained the other 4 layers with fair uniformity to a point a few centimeters from the basal end, where it was seen in 2 segments only, and came farthest in the outermost layer.

A basal section about 12 cm. long was left connected with the pump, and when the free end was dipped in color, liquid and color came through inside of a few minutes. No liquid came through the whole length. This is in accord with previous results in which no liquid was extracted by suction on the whole cross-section on any stem or root of the pine of a length of more than a few centimeters. On the other hand, liquid may be pulled through a root of the oak very quickly. A section a meter in length, 18 mm. in diameter at the large end, was connected with the pump, and the smaller end, 16 mm. in diameter, was dipped in a fuchsin solution. The pump was started, and as the column of mercury rose quickly in the barometric gage,

color was drawn in quantity through the root. This occurred within a few seconds and before the suction had reached that necessary to sustain a column of 700 mm. Hg. The dye was found in all layers, but most abundantly in the second from the outside.

## APPLICATION OF SUCTION TO ENDS OF LAYERS OF WOOD CARRYING WATER-COLUMN.

In view of the above facts, experiments were planned by which suction might be applied only to layers carrying the column of ascending water, with the avoidance of complications arising from the action of the body of gases in older wood or vessels.

*June 18.* A small redwood tree, 15 cm. in diameter at the base, was cut near Rocky Creek, 16 miles from the Laboratory, the stem was cut higher up and the 2-meter length thus secured was securely and quickly sealed at both ends with a heavy oil which was also applied to the stumps of branches. The preparation was brought to the Laboratory. A few hours later, the base was neatly trimmed with an axe and stepped into a vessel containing water. On the following day a hole 8 mm. in diameter and 8 cm. in depth was bored in the apical end in such manner as to tap the seventh, eighth, and ninth layers. A short section of tube was screwed securely in place and connected by pressure hose with an air pump (fig. 14). The stem was excentric, and the layers were thin, the outermost four being not much more than 1 mm. in thickness. The base was stepped into a vessel of acid fuchsin at $2^h16^m$ p. m., and the pump quickly raised a pressure that sustained a barometric column of 740 mm. Hg., and liquid was drawn from the bore almost immediately. The final length of the stem was 1.8 meters and a core the size of the bore-hole from end to end would have had a volume of 90 ml. During the course of the first two hours, 240 ml. of liquid were drawn out of the stem and the flask was so nearly filled that the pump was stopped. The barometric column dropped rapidly. The preparation was allowed to stand over night. The pump was started at $7^h55^m$ a. m. and water appeared in the tube screwed into the bore within 90 seconds. At the end of an hour in which the pressure held up a column of Hg. 740 mm. in height, 90 ml. of sap had been extracted; 240 ml. had accumulated in the flask up to the beginning of this period.

The pump was operated from 9 a. m. to 12 noon during which time 190 ml. additional sap was collected, a total of 420 ml. in 6 hours' operation. It is estimated that the dye came through after 5 hours, when about 400 ml. of sap had been drawn out. The bore extended the length of the section and would have a volume of 90 ml. This would imply that the sap of a tract five times the volume of the core had been extracted and that the longitudinal movement was at an average rate of 36 cm. per hour.

The preparation was allowed to rest an hour, then the pump was operated for an hour, during which time 100 ml. of sap was extracted, 152 ml. in all. It is to be seen that the amount so drawn out is greater in an hour than an average of a 2 or 3 hour run of the pump. The slower rate may be attributed to the depleted condition of the conduits after an extended run of the pump. The barometer column attached to the system was maintained singularly near 740 mm. during the 6 hours of the experiment, and no change in resistance could be detected. The pump was now connected with a similar bore-hole in a radius about 100° from the first and opening chiefly in the fourth, fifth and sixth layers. Liquid was seen in the tube within a few

seconds after the pressure of suction ran up to 740 mm. Hg., and the rate of extraction was obviously more rapid. The pump was stopped at the end of an hour and 180 ml. of liquid was measured in the receiver. The high rate of extraction is attributed to connection with more recently formed wood in the second bore than in the first. No color was seen in the last extract.

The pump was operated on the following day after a rest of 16 hours. 270 ml. of sap were extracted in the first 100 minutes, which was at the rate not widely different from that shown by the same bore on the previous day. Dye appeared in the extracted sap when this amount had been drawn out from the bore. It was noted that the resistance remained about the same, the manometer column standing near 740 mm. Hg. throughout.

The pump was now operated another hour, when a tinge of color was seen in the extract. Its apparent rate of transmission had been at the rate of

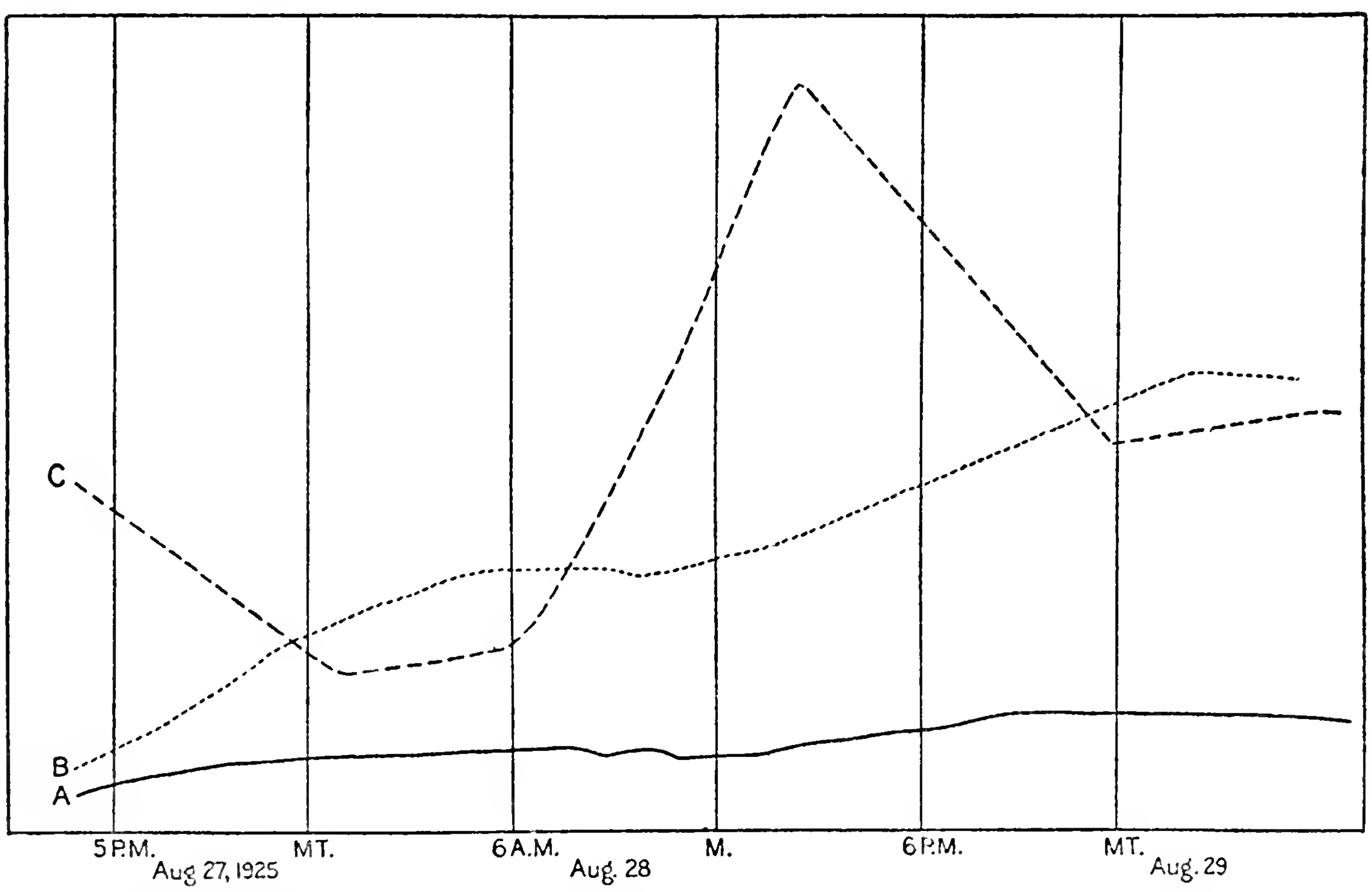



FIG. 13.—Range of air-temperature and of suction in Monterey pine No. 6. A, suction in tangential bore with only slight progressive increase, and only slightly lessened during period of high air-temperature. B, suction by stub of branch, increasing progressively and lessened during period of high air-temperature.

45 cm. per hour, though this may be subject to some correction by the diffusion of dye upward in the stem. 180 ml. of sap had been extracted, showing a fairly uniform rate. The earlier part of the extract, the first 200 c.c., had an opaline tinge.

A new bore 3 mm. in diameter and 3 cm. deep was now made in the third and fourth layers, equidistant from the two previous bores. The pump was operated for an hour and 12 ml. of sap was extracted. The preparation was allowed to rest 20 hours, when the pump was operated for 2 hours, during which the resistance as indicated by the barometric column sustained was 750 mm. Hg., which was slightly greater than in previous operations. About 25 ml. of sap were extracted in this 2-hour run. Dye was pulled farthest in young small stems rather than in old ones (Publ. 350, p. 31 and p. 82) and conduction was greatest in the second layer in some cases, and in the fourth in others (2 yrs. old?). (See also Publ. 365, p. 20.) The pump was

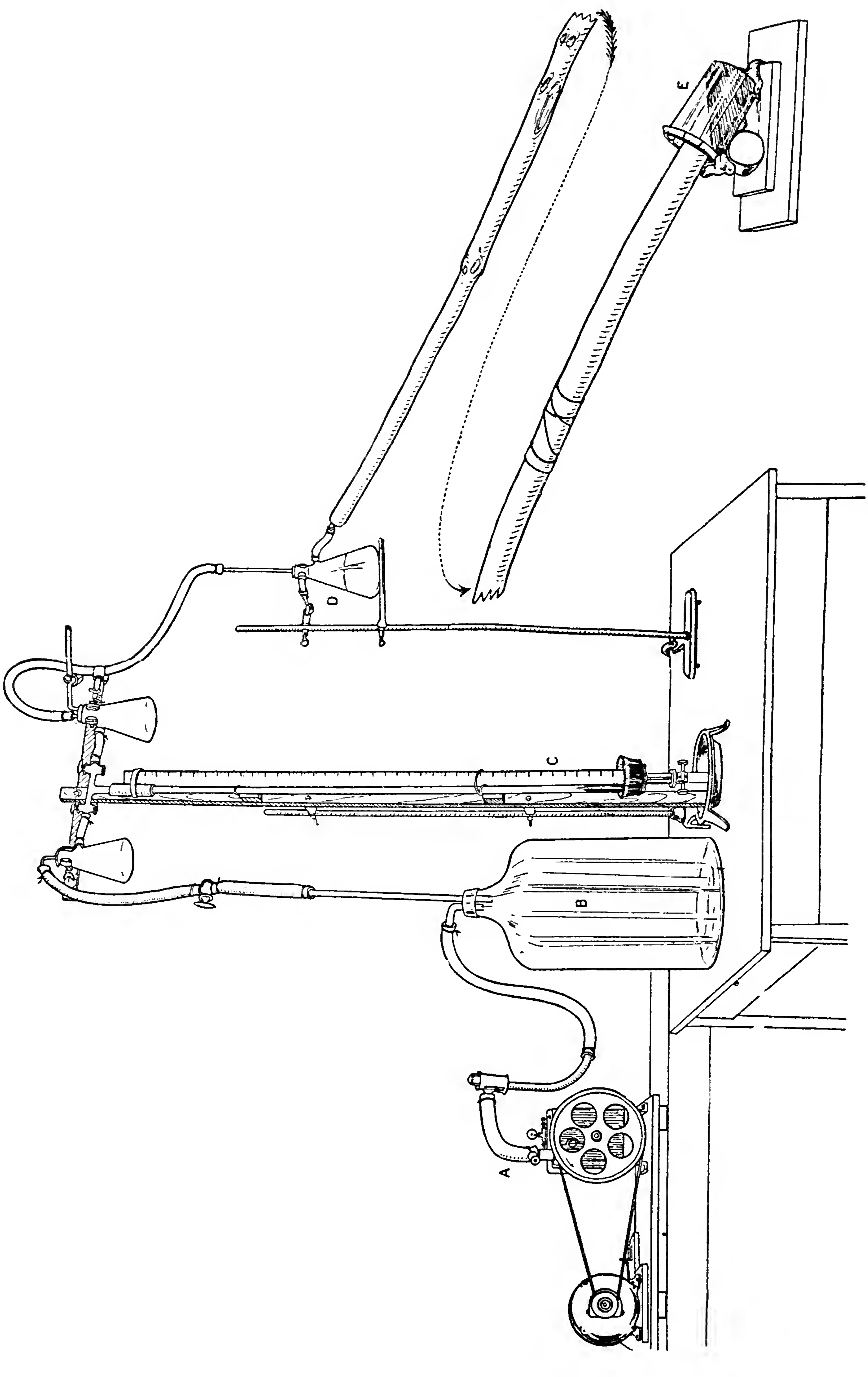



Fig. 14.—Arrangement for drawing sap from separate layers from trunk of pine tree. A, Nelson rotary pump, B, exhaust chamber, connected through two flasks to receiver D. A vertical glass tube with scale standing in a cistern of mercury serves to measure vacuum. Bottom of trunk stands in a watery solution E.

started again after only a few minutes' intermission, the resistance rising quickly to about 750 mm. Hg. Dye was seen in the extract after about 4-hours' operation of the pump. Calculated on the basis of the entire length, the color had moved at the rate of 45 cm. per hour. The pressure of the dye in the lower part of the section would make a slightly amended estimate. The pump was now stopped. The barometric column fell slowly and after 3 hours a total of 65 ml. of sap had been extracted. This amount was drawn out in one hour of full pressure (750 mm. Hg.) and 3 hours' lessening pressure, which was down to 250 mm. at the end.

Dissection of the stem at this time showed that the dye had ascended in all layers about 60 cm., or one-third the length of the section. Above this the three conducting tracts leading to the bore-holes were plainly marked. Midway of the stem, the first two and larger streams had enlarged by diffusion to give color to a strip 3 or 4 cm. tangentially and in 6 to 8 layers. The strictest channel was, of course, the most recent, leading to the smallest bore; 20 cm. from the terminus it was but 1 cm. in width tangentially, and occupied but one layer of wood, that of the previous year. The dye leading to the larger bores made in inner layers had not diffused sufficiently to be visible on the freshly bored surface for 30 cm. below the end.

The layers stained seemed to be determined in part by those tapped, and modified by tangential and radial diffusion. Movement in a radial direction is least. Not more than one or two layers inwardly or outwardly from the conduits connected with the bore receive the dye. An acidity test of the extracted sap from the second bore showed it to be pH 6.4, or very nearly neutral.

The first use of the above method of application of suction directly to the layers carrying the water-column was made on June 12, 1925, when the basal end of a section of a trunk of a Monterey pine 180 cm. long, 10 cm. diameter at the base, 7 cm. at the upper end, cut on the previous day, was stepped into a dish of water, and the upper end as well as surfaces of stumps of branches coated with a stiff lubricating grease. This was done to prevent water-loss and, also, to provide for the least conduction. On the following morning a hole 8 mm. in diameter and 25 deep was bored longitudinally in the wood of 1923 and 1924. A short section of metal tube was screwed into this hole and connected with the air pump. The surface around the tube was sealed securely. A short section of the base was cut off cleanly with the saw, and this was stepped into a vessel containing acid fuchsin 1-1000 in water. When the pump was started the system was exhausted to sustain 740 mm. Hg. within a few seconds. The first drops of liquid drawn into the receiver were tinged with the dye. This occurred within 5 minutes, so much sooner than expected that the time was not noted more exactly. Liquid had, therefore, been drawn up through the stem by an unbalanced pressure of 0.97 atmosphere; in connection with a lessened vapor pressure at the upper end this rate would be 36 cm. per minute.

Sap was drawn out as the pressure in the system, after being cut off from the pump, fell to 720 mm. Hg.

After the method had been used with such signal success with the redwood, a long series of tests were made with the Monterey pine to test the rate and path of conduction, to obtain sap from the separate layers, and to measure further the effects of suction directly to the sap-carrying layers.

*June 24.* A small pine 10 meters in height was cut off near the base, the surfaces smeared with heavy grease, and a section 2.35 cm. long brought into the Laboratory. The base showed 12 annular layers, and the apical end, which was 10 cm. in diameter, 8 layers. A bore 6 mm. in diameter was made

into the second and third layers from the upper end. These layers had a thickness of 5 and 11 mm. respectively. A brass tube was screwed into this hole and connected with the air pump. A short section was sawed from the base, which was stepped into a vessel of fuchsin at once.

The pump was started at $8^h28^m$ a. m. and the pressure was raised to 740 mm. Hg. within 10 seconds. Within 30 seconds liquid appeared in the tube inserted in the bore. At the end of an hour 120 ml. of liquid had been drawn out. The pump was started again at $9^h40^m$ a. m. At $11^h15^m$ a. m., 265 ml. of sap had been extracted, at a rate of about 165 ml. per hour, which was slightly greater than during the first hour. The connection was refitted, and the pump started again at $11^h20^m$. Some color was visible in the first sap that came, which ran into the flask undiluted. It could, therefore, be said that the color came through in 2.75 hours. The length of the stem was 2.35 meters. The rate, therefore, was over 95 cm. per hour.

Two days later the dissection of the stem showed that the dye had been drawn up in amount sufficient to leave a stain in a wide sector drawn by suction in the larger bore, which tapped the second and third layers. The effects of suction on the outer layer were not determinate. The heavy nodes and twisted wood made it impossible to connect another streak of color with the smaller bore, though it was probably caused by the action of the pump.

A small tube (fig. 8A), external diameter 3 mm., was inserted in bore in external layer formed in the current year. The pump was started at $11^h45^m$ a. m. At 2 p. m. 112 ml. of sap had been extracted, which was at the rate of 50 ml. per hour. An analysis of this extract from the outermost layer showed a content of reducing sugars of 0.27 gram per 1,000 ml. sap and an acidity of pH 5.6.

The sap of the first sample taken from the second and third layers 3 hours previously had a sugar-content of 0.1644 gram per 1,000 ml. sap and pH 5.4. A second sample, obviously diluted, had a sap pH 5.5 and a sugar-content of 0.1336 gram per 1,000 ml. of sap.

The pump was operated on the small bore in the outermost layer from $11^h45^m$ a. m. until 2 p. m., then from 2 to $3^h45^m$ p. m., at which time color was seen. The pump was stopped after 4 hours' total operation, leaving the bore-hole connected with the chambers evacuated by the air pump and standing at 740 mm. Hg. This was seen to fall but slowly by withdrawal of material from the stem.

On the following morning, the column of Hg. exerting a suction on the stem had fallen to 0. The operation of the pump for 1.75 hours and the subsequent lessening pull of the barometric column had extracted 75 ml. of sap. No color was apparent after a total maximum suction of 5 hours in addition to this decreasing pull.

The amount of liquid collected was equivalent to that which would be extracted in 3.5 hours' operation of the pump. It may be said, therefore, that extraction of sap from this outermost layer for nearly 6 hours failed to draw color through the stem. This was in the basal part in which fuchsin does not often diffuse upwardly at any rate comparable to that by which it ascends in older layers.

The section of the trunk 2 meters in length was now taken for examination. The basal end had stood in a vessel of water for 48 hours. The heavy branches had been trimmed from the four nodes included. The stumps and the upper end had been thickly coated with heavy grease where the cuts were made. The upper end was 65 mm. across, showing 6 layers of wood, of which the outermost was 54 mm. in thickness. The small tube was inserted in a bore 5 mm. in diameter and 3 cm. long in this layer, and the pump was started

at $7^h40^m$ a. m. Within a minute extraction was to be seen. The base of the section was in a vessel of fuchsin 1-1000 in water.

In 2 hours 60 ml. of sap were drawn off from the outer layer. The tube was reset in the second layer and the pump started at $9^h30^m$ a. m., the pressure rising to 740 mm. at once and sap flow occurring within a few seconds. The first sample from the outer layer had a sugar content of 0.2 gram per 1,000 ml. with pH 5.4.

The extract during 2-hours' operation of the pump, with the small tube connected with the second layer, amounted to 72 ml. The tube was now connected with a bore in the third layer at $11^h30^m$ a. m. At 2 p. m. a total of 195 ml. of sap had been extracted, which was at the rate 78 ml. per hour. This was greater than the rate in the first layer, which was 30 ml. per hour, and the second layer, 36 ml. per hour.

The sap from the second layer had a sugar content of 0.0538 gram per 1,000 ml. with pH 5.6. The sap of the third layer had a sugar content of 0.0696 gram per 1,000 ml. sap. The fitting was operated on the fourth layer from 2 p. m. to $4^h15^m$ p. m., obtaining a total extract of 90 ml. of sap in 2.25 hours, which was extraction at a rate of 40 ml. per hour. This sap had a sugar content of 0.0618 gram per liter and an acidity denoted by pH 5.4. The pump was stopped at 4 p. m. and the bore (in the fourth layer) was allowed to remain in connection with the collecting flasks, which had a total capacity of about 1.5 liter. The slow equalization of this pressure took place during the night with the extraction of about 130 ml. of sap. The system was again exhausted and allowed to draw on the stem with slow equalization. This was begun at $7^h30^m$ a. m. Three hours later the mercury had fallen to 150 mm., and extraction was still going on very slowly, during which time 70 ml. of sap had been extracted. During the previous night total equalization had extracted 100 ml. The pump was now operated to bring the mercury column up to 200 mm. at $10^h30^m$ a. m. when the connection was cut. By inference 30 ml. of sap had been extracted below this pressure during the previous night.

It is to be noted that extraction of the liquid was accompanied by a continuous appearance of air-bubbles. These were probably gases released from solution under the lessened pressure.

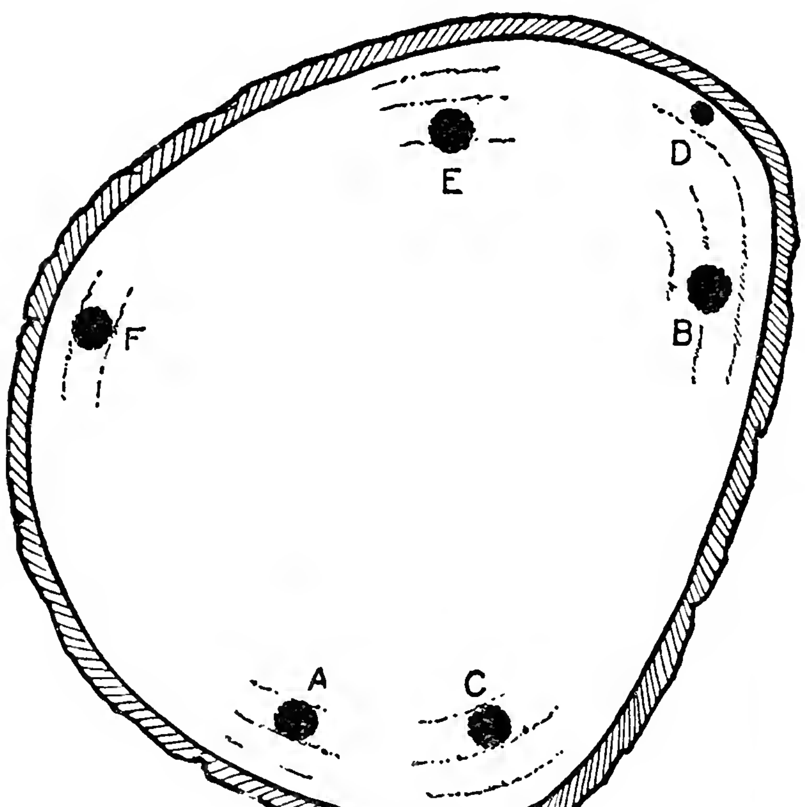
The pressure ran down from 120 to 40 mm. in 5 hours, with only a slight extraction of material. Resistance varies enormously with speed. It is to be inferred that an actual movement of liquid in a stem 2 meters long may be produced by as small a suction as that of a column of Hg. 40 mm. in height or 0.05 atmosphere, a point to be determined later.

On the following day a bore 8 mm. in diameter was made, mainly in the second layer, which probably also connected with some wood in the third. The pump raised a column of only 610 to 620 mm. Hg. in the extended system of flasks. Liquid was drawn out within 20 seconds of the starting of the pump. 70 ml. had been collected at the end of 26 minutes and 170 ml. at the end of an hour. No color was seen in this time. The stem included four nodes with stumps of heavy branches, and conduction would be variously complicated.

The dissection of the stem showed color in the inner part of the first layer in one sector, and parts of the second and third on separated sectors, none of which could be connected directly with any of the bore-holes in the upper end, through the heavy nodal structures.

## MODIFICATIONS OF PRESSURES INDUCED BY SUCTION APPLIED TO ENDS OF STEMS, AND TO SAP-CONDUCTING LAYERS.

The results of the experiments described in the previous section make it evident that suction on the terminal end of any conducting tract is communicated longitudinally through the trunk of the pine with but little effect on neighboring wood. The effect seems to be more diffused in *Sequoia.* The slight suction force necessary to draw liquid through a section of the stem was demonstrated. Dyes were conducted at much higher rates than in any experiment in which the exhaust was applied to the entire cross-section. When this is done with a short section of a stem, the central air-body may be drawn out more or less completely and the stem infiltrated to such an extent that transmission or conduction may then go on as rapidly as in the method by which suction is applied to conducting layers only. Such action may be connected with the results of experiments previously described,

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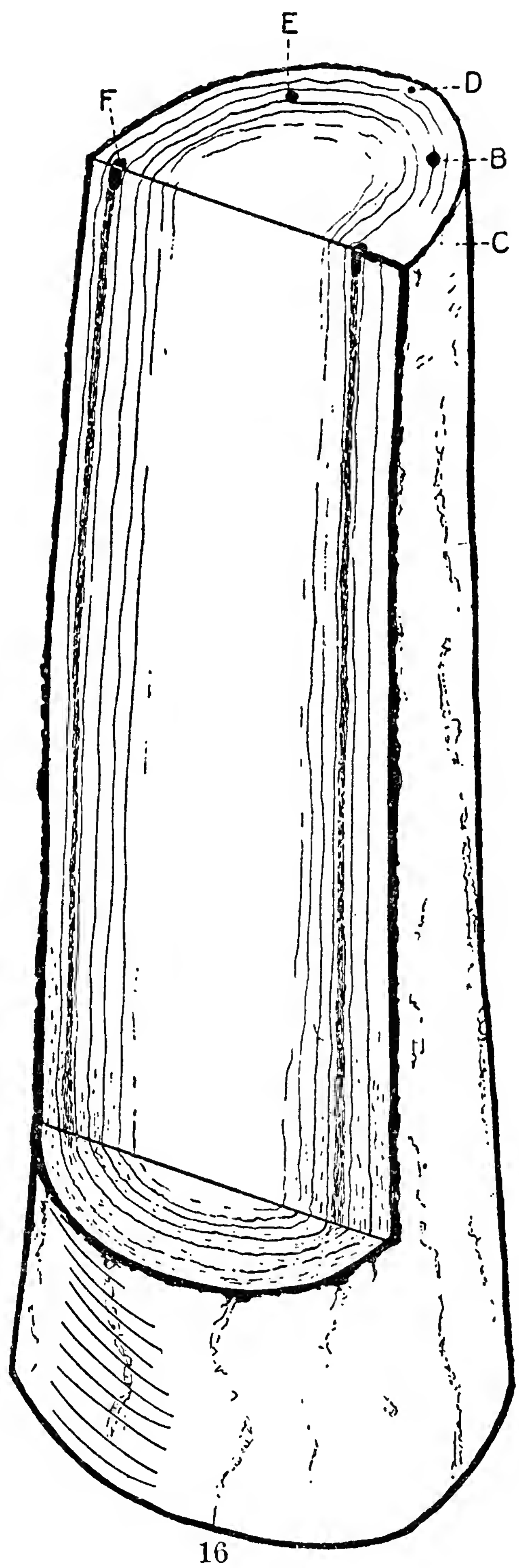


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Fig. 15.—Diagram showing relative positions of bores used for extracting sap and measuring suction in separate layers of small pine trunk. (See Fig. 16.)

Fig. 16.—Scheme of trunk, a diagram of end of which is shown in Fig. 15. The strict conduction of sap to bores F and C is denoted by heavier shading.

in which suction applied to the entire end of a short section of stem resulted in no extraction for an hour or two, at the end of such period liquid being drawn through the stem in quantity. It is evident that in the specialized application of suction to sap-conducting layers, a method has been found by which a variety of critical tests of the forces concerned in the ascent of sap may be made.

*July 20.* Small stocky tree of *Pinus radiata* was cut and the basal section of trunk 2 meters in length was stepped in a vessel of fuchsin. The stumps of branches and upper end were sealed with a hard grease (figs. 16 and 17).

A manometer with open end was sealed into a bore (fig. 15 A; cut away in fig. 16) made in the third layer 8 mm. in diameter at $8^h30^m$ a. m. Readings were made as follows:

Table 11.

| | | | |
|---|---|---|---|
| July 20, | $8^h38^m$ | a. m. | −7 mm. Hg. |
| | 10 | a. m. | — —. Some air released; set to 0. |
| | 10 12 | a. m. | −10. By sudden visible action. |
| | 10 18 | a. m. | −18. |
| | 11 05 | a. m. | −15. |
| | 2 15 | p. m. | −14. |
| | 4 | p. m. | A bore-hole 4 cm. (fig. 15 and fig. 16 C) deep was made in the third layer, the sides of which were 20 mm. distant from the sides of the bore to which the manometer was attached and connected with the pump. |
| July 20, | 4 30 | p. m. | −14. 55 ml. extract which had a sugar content of 0.69g per L., and pH of 5.7. |
| July 21, | 7 | a. m. | −11. |

A minute tube (fig. 8 D) with a bore of 1.5 mm. was fastened in a hole in the outermost layer on the opposite side from the manometer opening at 9 a. m. When the pump was connected and started sap was seen in the tube within 7 minutes. The flow, however, was very slow. Five hours later less than 25 ml. of sap having been obtained, the tube was dismounted and cleared, then re-inserted, and the pump started again. At 4 p. m. 50 c.c. of sap had been extracted. This had a sugar content of 0.49 gram per liter, and an acidity denoted by pH 5.6.

Table 12.

| | | | |
|---|---|---|---|
| July 22, | $7^h18^m$ | a. m. | Suction −12.5. |
| | 8 30 | a. m. | Do −15. |
| | 9 | a. m. | Do −17.5. |
| | 9 18 | a. m. | Suction. Accumulated sap 250 ml. in 2 hrs. Pressure down in changing to 16 mm. |
| | 11 | a. m. | Suction −17 mm. Taken down 200 ml. sap. Pressure in manometer decreased 1 in 10 minutes. |
| | 11 10 | a. m. | Started again. Suction ranged 740–745 mm. Hg. to −7, a further diminution of 9 mm. in manometer. |
| | 2 30 | p. m. | Suction −20. 420 ml. liquid taken out, tinged with color. New bore and connection, E; manometer set at 0. New bore 30 mm. from old. |
| | 3 30 | p. m. | Suction −14 mm. Hg. in manometer. |
| | 4 30 | p. m. | Suction −20. 180 ml. taken out. Pressure down 1 mm. in 5 minutes. Reset. |
| | 6 30 | p. m. | Suction −26. |
| | 9 30 | p. m. | Do −26. Pump stopped, dye in extract. |
| July 23, | 7 | a. m. | Do −10. 240 ml. extract of night before. |

The pump was set in a new bore, E (figs. 15 and 16), diametrically across from the manometer. In 2-hours' operation extraction was at a low rate,

which is to be coupled with the fact that the lowered level of the liquid in the vessel had bared the lower end of the stem. It was covered with water at $9^h40^m$ a. m. The manometer which stood at −10 had been changed to −12 in the pumping. But little sap was extracted.

The dissection of the stem showed that dye which started in the second and third on July 22 at $7^h18^m$ a. m., had been carried up in the third and fifth layers toward the bore-hole, C. The dye had appeared in the extract at $2^h30^m$ p. m. after 7-hours' operation of the pump, which gave conduction at a rate of about 25 to 30 cm. per hour. When the stem was dissected on the following day, color was visible to a total length of about 175 cm. in the third and fifth layers, although colored liquid had been sucked through as noted. Dye had been pulled through another bore, B, in the two outer layers in something less than 5 hours, but in such quantity that the wood was stained in the two outermost layers the entire length of the stem, indicative of a higher rate of conduction.

The apparatus was now transferred to the freshly cut basal section of a tree with an excentric trunk 240 cm. long. The manometer was attached to a bore in the thin outer layers, and the pump to a bore diametrically across. The section was 18 cm. in diameter at base and 15 cm. at the upper end, which was well-coated with grease.

The absorption pressure in the manometer was raised to −18 mm. Hg. within 5 minutes without the use of the pump. 15 minutes after starting it showed a suction of −39 mm. Hg. At $11^h45^m$ a. m., 25 minutes after setting up, the pressure had fallen to −18 mm. Hg., and at 2 p. m. to −10 mm. Hg.

The pump was started at $11^h20^m$ a. m., and sap showed in the tube within a few seconds. Extraction proceeded at a comparatively low rate, but color appeared in the extract in 3 hours, giving a conduction rate of 80 cm. per hour.

*July 23.* At $3^h35^m$ p. m. much air had accumulated in the manometer, and it was released. The mercury was set at 0, and immediate absorption was visible, which ran to −8 mm. within 3 minutes.

The manometer at $4^h30^m$ read −10 mm., and was apparently unaffected by the action of the pump. The receiver was emptied of 370 ml. of sap, and the pump started again at a pressure of −756 Hg. The pump was stopped at 11 p. m. that evening, and 800 ml. of sap taken from the receiver the next morning, about 1,200 ml. in all from this bore. This appeared to be an acceleration of the rate of extraction. It has been found previously many times that the rate of extraction rises after the base of such a cut stem has stood in watery solution for several hours. Extraction from this bore was continued.

The manometer had come to 0 with air accumulated in the vertical release tube. The air was released and the mercury set to 0. Almost immediately suction pressure showed. The readjustment was made at $8^h15^m$ a. m., and a suction of −15 mm. Hg. showed within 15 minutes, which was taken to be unaffected by the suction of 760 mm. in the pump bore, diametrically across the trunk. At 10 a. m. a suction of −18 mm. showed on the manometer.

At $11^h30^m$ 350 ml. of extract was removed and the pump started again. The manometer stood at −18 mm. Some air was removed, and the column reset to 0.

At 2 p. m. 290 ml. of sap had been extracted. Connection was made with a new bore 40 mm. distant and the pump started at $2^h30^m$ p. m. Manometer reset to 0 again after release of air.

4 p. m. 140 ml. of extract removed. Manometer reading −2, not seemingly affected by pump action.

8 p. m. No pressure in manometer. Pump stopped. 360 ml. of extract were taken out. Pump run to set up pressure, then stopped.

At 8 a. m. on the following morning no pressure was denoted by the manometer, but some air had accumulated. The mercury in the gage had fallen to 105 in the 12 hours since a suction of −750 had been set up in the system, which had a capacity of about 1.2 liter. This remaining pressure probably represents resistance at the velocity approaching the minimum in the movement of sap. 300 ml. of sap were taken from the receiver and the pump started again. Suctions as follows were recorded:

TABLE 13.

| | | |
|---|---|---|
| July 25, | $-12$ at $9^h30^m$ a. m. | |
| | $-36$ at 11 a. m., | with sun shining on log. 250 c.c. extract taken from receiver at this time. |
| | 3 p. m. | Manometer $-26$. 330 ml. of extract removed from receiver. |
| July 26, | $8^h30^m$ a. m. | Manometer stood at $-21$. Pump started. |
| | 9 30 a. m. | 290 extract removed. Manometer $-19$. |
| | 3 p. m. | 300 ml. extract taken out. Manometer $-17$ and no change resulted while pump was being fitted to new bore-hole, the side of which was 70 mm. from the manometer bore. New large plenum chamber incorporated in the vacuum series. |
| July 27, | 7 30 a. m. | Manometer $-21$. Some 200 ml. had been extracted by the vacuum over night. |
| | 11 a. m. | 440 ml. removed, and new hole bored as dye was beginning to come in. The pump was stopped before 6 p. m., and on the following morning 110 ml. of sap were taken out of the receiver. Some dye showed. |

Dissection of this trunk on August 8 showed the dye unequally distributed in many of the layers, comprising about three-fourths of the trunk, some diffusion doubtless having taken place in the 12 days in the water-filled wood since the pump was dismounted. A second cut, a third of the length, about 1 meter from the upper end, showed two stained tracts connected with the bore-holes. The tract connected with the first bore consisted of material in the second and third layers about 2.5 mm. in width, and the dye did not pass the last node and reach the end, although over 1.8 liters of sap were extracted through it. 2 liters of sap were taken from bore 2, and dye showed, although the wood was stained but half the length of the trunk. But 750 ml. extract were taken from bore 3 when dye showed, and the wood was stained the entire length when dissection was made 12 days later. Dye showed in the fourth hole when but 300 ml. of sap had been extracted.

*July 28.* The extraction tube was now fastened in a bore-hole of the upper section of the same tree, the lower end of which had been stepped in a solution of fuchsin the previous day, when all stumps of branches and the surface of the upper end had been thickly coated with heavy grease.

*July 28, $11^h00^m$ a. m.* 450 ml. of extract were taken from the receiver and at 2 p. m. 290 more. The last lot held some dye and a new bore-hole was made for extraction while a manometer was fastened in the one just left vacant.

*July 28, $3^h45^m$ p. m.* 180 ml. of sap taken.

*July 28, 8 a. m.* 360 ml. taken out. Moved connection to new hole. Bottom end of section dry and extraction could not be resumed in old bore. No extraction came in new bore until liquid had been poured into vessel to cover lower end of section. After 230 ml. of sap had been drawn out, the extraction was terminated.

About 1.4 liters were taken from the first bore in the upper section of the trunk. A third of the trunk in several layers was heavily stained in connection with this bore. Only 230 ml. of sap were taken from a second bore, and the wood was stained only half the length of the trunk in the third and

fourth layers. The dye had gone nearly to the end of the tract in the first bore, staining a width tangentially of 20 mm. in the third and fourth layers, in which the bore had been made.

*August 5, 2 p. m.* A small tree near entrance was cut, the branches taken off, the scars being sealed with heavy grease. The base, 27 mm. in diameter, was stepped in fuchsin. The apical end, 23 mm. in diameter, was sealed into a heavy rubber hose and the air-pump started at 3 p. m. After some difficulty in making the connection good, the suction was raised to −745 mm. Hg. After several minutes the stem was inverted, but no extraction had taken place in repetition of previous experiences.

A transverse cut was made in the stem 60 cm. from the base by means of a saw, which half severed the stem. This was filled with stiff grease which was liberally piled on the cut.

No extract in an hour.

Pump overset; connections and suction restored by $4^h30^m$ p. m., 745 mm. Hg., and pump stopped.

*August 5, $8^h30^m$ a. m.* The suction stood at −400 mm. from the previous day, showing good connections and high resistance. No extract. Pressure raised again to $7^h45^m$ mm.

*August 6, $2^h30^m$ p. m.* The suction set up 30 hours previously had fallen to −200 mm., and a few cubic centimeters extract had collected in the tube. The pump was now operated for a few minutes until the pressure again stood at −745 mm., after which it was stopped.

*August 7, 9 a. m.* Column stood at 300 mm. with only a few drops extracted. At 4 p. m., column down to −200 mm. Pump operated to bring pressure up. Several milliliters of extract seen.

*August 8, $8^h8^m$ a. m.* Exhaust column at 340 mm. Some extract. Stem dismounted for dissection. The dye had come up in all of the 8 layers of the stem to a short distance below the transverse cut, which was filled with grease in the ordinary manner of diffusion of such material. It stopped 7 or 8 cm. short of the cut in the inner layers, but showed in the two outermost to within a few millimeters of the groove. It did not show in the sector blocked off above. The stem was somewhat irregular and it was not easy to follow the course of the conduits, but it was apparent that the dye which disappeared from some of the inner layers of the uninterrupted half of the stem, above the node 25 cm. above the cut, had shown some circumferential diffusion in first and second layers in which it continued, so that the unstained section was reduced to about a quarter of the circumference, a meter above the cut. Above this, by reason of the ordinary inequalities of diffusion, the dye showed only in a decreasing section, coming down to a narrow ribbon above a node 25 cm. from the upper end of the cut stem, where the color showed only in the outer layer. It was notable that while the wood was stained to within 22 cm. of the upper end of the stem, no color appeared in the extract, of which no more than 100 ml. had been obtained in several hours at 745 mm. suction, and many more at diminishing pressures.

*August 11.* A small pine tree outside of the main entrance was cut, the base being 40 mm. in diameter. The branches were trimmed and the scars sealed with heavy grease. A section 1.8 mm. long was taken for test with the air pump. The base was fitted with a section of large rubber tube, tightly bound round it, in which a solution of fuchsin was placed, this arrangement allowing the stem to be held in a horizontal position while suction was being applied to the upper end, which had a diameter of 30 mm. A short section of heavy rubber hose was clamped round the upper end and connected with an air pump through a plenum chamber with a capacity of 20 liters.

It had been noted in previous experiments that suction might be applied to the upper end of a stem in this manner for many hours without any extraction of sap resulting. This would come only after the stem had stood with its base in liquid for several hours with suction at the upper end, while a tube inserted in the outer wood would draw sap in a few seconds with a vacuum holding up a mercury column of 745 mm. It has been held that the delay in extraction when suction was applied to the whole stem was due to the air cushion in the inner layers and medulla of the stem. It was therefore arranged to close off this air system and apply suction to the ends of the conducting wood supposedly filled with water. To accomplish this a bore 8 mm. in diameter was made in the central part of the stem to a depth of about 40 mm. This was filled with a stiff grease, then a short section of threaded bolt was screwed into the bore for the purpose of blocking off the entrance to the central air-filled wood. This, of course, could not be done perfectly or completely, but the experiments described below show that communication had been much restricted. A section of pressure connected with the air-pump was now clamped about the end of the stem thus prepared. Had the preparation been perfect, suction could have been exerted on the sap-carrying wood only. The pump was started at $8^h50^m$ a. m., and as the large plenum chamber was exhausted, extraction began within 10 minutes of the beginning of the operation, and within a much shorter period of high suction. Extraction continued with a decreasing rate until $11^h30^m$ a. m., when the exhaust gage stood at 300 mm. The pump was again operated to bring it up to 745 mm. At 7 p. m. the column had come down to 300 mm. The pump was again operated to exhaust the system.

*August 9, 8 a. m.* On the following morning the exhaust column had fallen to 180 mm., and a total of 150 ml. of sap was taken from the receiver. This sap had an acidity denoted by pH 5.6, and a sugar content of 1.2 grams per liter. The dissection of the stem showed a course of the dye much as in the previous stem. The color came in all layers stopping about 10 cm. short of a saw-cut, which half severed the stem. Above the cut, the dye first came into the inner layers and diffused circumferentially, until at a distance of a meter above the cut the dye had disappeared from the inner layers, showed in the three outer layers on the normal flank, and in the third and fourth layers only of the flank above the cut. Above the last node, the color had gone up in two strips in the outermost layers only which were connected with the stained wood of the normal flank below. The diffusion of dye had stained the wood a total length of about 160 cm. in 24 hours at a rate of less than 7 cm. per hour. It was not possible to detect any color in the extract.

*August 13, $8^h30^m$ a. m.* A small tree was cut near the entrance, the base and the scars of the branches sealed with stiff grease and a section 1.9 meters long cut from it. The basal end, 30 mm. in diameter, was kept moist and was quickly sealed into a section of reinforced hose, which was connected with a barometric gage. The hose and connections had been filled with a fuchsin solution. The stem being placed in a horizontal position, the mercury rose within a minute to 20 mm. above the level in the cistern, and at the end of 20 minutes had attained a further height of 30 mm. above it. Meanwhile, the upper end of the stem had been sealed into another section of hose connected with an air pump with its gage, but the pump was not operated until later as noted below. Meanwhile, the suction into the base of the stem was denoted by the readings shown in Table 14.

TABLE 14.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 13 | $8^h55^m$ a. m. | − 45 | |
| | 9 a. m. | − 50 | |
| | 9 05 a. m. | − 55 | |
| | 9 10 a. m. | − 60 | |
| | 9 15 a. m. | − 65 | |
| | 9 20 a. m. | − 70 | |
| | 9 25 a. m. | − 74 | Disturbed and came down to −65. |
| | 9 30 a. m. | − 70 | |
| | 9 45 a. m. | − 75 | Pump started. |
| | 9 50 a. m. | − 85 | Exhaust −700 mm. Hg. |
| | 9 55 a. m. | −100 | Do. −745 mm. Hg. |
| | 10 a. m. | −110 | Do. −755 mm. Hg. |
| | 10 05 a. m. | −116 | Do. −756 mm. Hg. |
| | 10 10 a. m. | −122 | Do. −756 mm. Hg. |
| | 10 30 a. m. | −143 | Do. −755 mm. Hg. |
| | 10 45 a. m. | −160 | Do. −754 mm. Hg. |
| | 11 a. m. | −180 | Do. −753 mm. Hg. |
| | 11 40 a. m. | −200 | Do. −745 mm. Hg. No extraction of sap. |
| | 1 45 p. m. | −290 | Pump operated to bring pressure to −720. Extraction began $6^h50^m$ p. m. |
| | 4 p. m. | −360 | Pump operated to bring exhaust to −740. Some extraction. |
| | 7 p. m. | −425 | Exhaust −675 mm. Pump operated 15 minutes. |
| | 7 15 p. m. | −430 | Do. −755 mm. |
| | 7 30 p. m. | −435 | Do. −750 mm. |
| | 7 45 p. m. | −440 | Do. −748 mm. |
| Aug. 14 | 5 45 a. m. | −455 | Do. −475 mm. Pump operated. |
| | 6 a. m. | −456 | Do. −755. Air in manometer; reset to 0 and pump started. |
| | 6 33 a. m. | − | Immediate suction through stem as column connected with plenum chamber rose. |
| | 6 53 a. m. | −170 | Exhaust −745 mm. |
| | 7 a. m. | −240 | Do. −730 mm. |
| | 7 12 a. m. | −290 | Do. −715 mm. |
| | 7 35 a. m. | −350 | Do. −680 mm. Pump operated to bring exhaust to −740; extraction proceeding. |
| | 8 a. m. | | Air in manometer reset at −165 and pump operated to bring exhaust up to −740. |
| | 8 30 a. m. | −390 | Exhaust 695. |
| | 9 30 a. m. | −440 | Do. 745. |
| | 9 50 a. m. | −450 | Do. 725. Pump operated to −745. |
| | 10 50 a. m. | −465 | Do. 670. |
| | 11 15 a. m. | −470 | Do. 720. |
| Aug. 15 | 9 45 a. m. | −365 | Do. 10. Air released; manometer and exhaust reset to 0. Pump started $9^h55^m$ a. m. |
| | 10 05 a. m. | − 80 | Exhaust 740. Some extraction. |
| | 11 30 a. m. | −315 | Do. 620. Pump operated. |
| | 12 15 a. m. | −375 | Do. 742. |
| | 2 p. m. | −435 | Do. 600. Pump operated. |
| | 2 25 p. m. | −445 | Do. 740. |
| | 3 15 p. m. | −460 | Do. 675. Pump operated. |
| | 4 p. m. | −475 | Do. 740. |
| | 5 30 p. m. | −495 | Do. 740. |
| Aug. 16 | 7 30 a. m. | −405 | Do. 75. Pump operated to bring exhaust to 740 and air released from other instrument, allowing column to fall to 438. |
| | 9 a. m. | −440 | Exhaust 740. |
| | 9 40 a. m. | −470 | Do. 700. Pump operated. |
| | 10 40 a. m. | −490 | Do. 740. |
| | 12 15 p. m. | −498 | Do. 633. |
| | 4 p. m. | −415 | Do. 360. Pump operated. |
| | 4 15 p. m. | −420 | Do. 740. |

Table 14—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 17 | $7^h20^m$ a. m. | −200 | Exhaust −60. Air released; manometer set to 0 and pump started. |
| | 7 24 a. m. | − 40 | Do. −680. |
| | 7 27 a. m. | − 90 | Do. −735. |
| | 7 30 a. m. | −125 | Do. −745. |
| | 7 45 a. m. | −255 | Do. −750. |
| | 8 a. m. | −330 | Do. −725. Pump started and operated continuously. |
| | 8 20 a. m. | −380 | Do. −745. |
| | 8 35 a. m. | −425 | Do. −745. |
| | 9 a. m. | −452 | Do. −745. |
| | 9 30 a. m. | −475 | Do. −748. |
| | 11 a. m. | −505 | Do. −748. |
| | 11 45 a. m. | −510 | Do. −748. |
| | 1 45 p. m. | −520 | Do. −748. Pump stopped. |
| | 3 30 p. m. | −455 | Do. −620. |
| | 4 50 p. m. | −510 | Do. −565. |
| | 5 15 p. m. | −503 | Do. −501. |
| | | −498 | Do. −480. |
| | 5 30 p. m. | −495 | Do. −470. |
| Aug. 18 | 8 a. m. | −405 | Do. − 50. |

The temporary rise after 3.30 p. m. August 17 is not explainable. The slow fall of the column at the end of the trunk is due to the resistance to the entrance of air from the exhaust chamber in which the pressure was seen to approach atmospheric, and was within 50 mm. of it on the following morning. Presumably the stem was more nearly infiltrated with water than before. The pump was now started again at 8.30 a. m., and readings made as follows:

Aug. 18, $8^h50^m$ a. m. −452 mm. Hg. suction into base of stem. Exhaust −748.
9 30 a. m. −455 mm. Hg. suction into base of stem. Exhaust −748.

The exhaust chamber was disconnected, the receiving flask turned up to immerse the end and thus allow water to be drawn in, instead of air, as the column at the basal end of the trunk fell.

At $10^h30^m$ the manometer was at −405 mm. and no noticeable difference could be seen. Exhaust was now released at upper end formerly connected with the pump, and this end was supplied with water at atmospheric pressure, the other end arranged to show any suction. This was manifest at once and the column in the manometer had been drawn to −85 mm. at 11 a. m. At $11^h25^m$ the column had risen to 100 mm. At 12 noon the column had fallen to 90 mm.; at 2 p. m. it had come down to −25 mm., with marked absorption of water at the upper end.

The figures given illustrate the fact that after treatment for 5 days as implied in the preceding tests, water entered the stem as by capillarity or suction pressure. While water was being allowed to enter one end from an open funnel, it was being taken in at the other with a force which raised the column of mercury to 100 mm.

The chamber with a capacity of 20 liters was now exhausted to sustain a column 745 mm. in height. When this had been done, the stopcock was turned to connect it with the leading tube at the upper end of the stem. Suction in the manometer attached to the base rose to −20 mm. within 30 seconds. The pump was now operated for 40 minutes with the manometer

at the base of the stem reading −205 mm. At 7 a. m. on the following day the exhaust had fallen to −355, while the column in the manometer at the other end of the stem, having been raised by the exhaust, showed a lag in falling so that it stood at −420 mm. Operation of the pump at 11$^h$45$^m$ a. m. for half an hour resulted in an exhaust of 740 mm. and a manometer reading of 460 on the stem. Two hours later the exhaust had fallen to −700, but the stem-manometer stood at −470 mm.

TABLE 15.

| Date. | Time. | Exhaust. | Stem-manometer. | Remarks. |
|---|---|---|---|---|
| 1925 | | | | |
| Aug. 20 | 8$^h$00$^m$ a. m. | −260 | −420 | Pump operated for a few minutes to bring exhaust to −740. |
| | 9 a. m. | −740 | −425 | |
| | 11 a. m. | −745 | −430 | Pump operated for a few minutes. |
| Aug. 21 | 1 30 p. m. | −185 | −355 | |
| Aug. 22 | 1 30 p. m. | ......... | −350 | Pump disconnected. |
| | 4 p. m. | ......... | ............... | Reset to 0. |
| | 5 p. m. | ......... | − 60 | |
| Aug. 23 | 8 a. m. | ......... | −180 | |
| | 11 a. m. | ......... | −170 | |
| | 4 30 p. m. | ......... | −155 | |
| Aug. 24 | 7 30 a. m. | ......... | −215 | |

The preparation was now dismounted and the stem dissected. The dye had stained all layers to the first node, a length of a meter from the base. Above this the color began to show a lessened density in the inner layers, and at 30 cm. from the end was present in the two outer layers only; extreme extension of the dye was in the outermost layer.

A repetition of this experiment seemed desirable, and another small tree was cut and the upper end to which suction was applied was bored and plugged centrally as follows:

*August 19.* A small pine near entrance was cut down, the branches taken off, the scars sealed with grease as well as the base of the stem, and taken into the laboratory. A short section of the base was sawed off, and a section of pressure hose clamped over it and sealed. This was filled with water and connected with a vertical tube standing in a mercury column at 9 a. m. The base was 27 mm. in diameter and showed 8 layers of wood. The top was cut at a distance of 3.5 meters from the base. This terminal end was in the internode formed in 1924 and was about 14 mm. in diameter. A hole 8 mm. in diameter was bored longitudinally to a depth of 3 cm. from the center to remove pith and protoxylem, filled with stiff grease, then a threaded metal plug was screwed in to complete the seal. The outer part of the wood of 1924 and the wood of the present year were left exposed.

At 10 a. m. the mercury, which had been adjusted at the same level in the tube as in the cistern, had been pushed out of the tube and some air had come out of the base of the stem. At 10$^h$45$^m$ a. m. active absorption had begun and a column 70 mm. had been pulled up in the manometric column. Other readings are given in Table 16.

Extraction of sap from ends of branches and stems of conifers by suction is attended with difficulty when suction is applied to the entire cross-section. Expansion of gases in the central gas-filled conduits and wood results from the suction at first. If the free end of the stem is immersed in liquid this is gradually drawn in, and after the stem is approximately infiltrated extraction may begin. Suction applied in this manner causes only slight acceleration of the movements of days in the ascending sap meshwork or column.

TABLE 16.

| | | | |
|---|---|---|---|
| Aug. 19, | $11^h45^m$ | a. m. | Stem −75 mm. |
| | 1 45 | p. m. | Stem −68 mm. |
| | 4 | p. m. | Stem −68 mm. Reset to 0; air released. |
| Aug. 20, | 8 | a. m. | Stem −50 mm. |
| Aug. 21, | 1 | p. m. | Stem −48 mm. 0. Air released. The pump was now connected to the pressure tubing clamped at upper end and suction was applied to determine effect of such suction on further end of stem. |
| Aug. 21, | 1 45 | p. m. | Pump connected and operated; exhaust suction at basal end. |
| | 4 30 | p. m. | Exhaust −670. Stem −8 mm. |
| | 4 40 | p. m. | Do. −742. Stem −12 mm. |
| Aug. 22, | 8 | a. m. | Do. −290. —. Air taken out of system at basal end of stem; mercury set at 0. Pump started at $8^h15^m$ a. m. and stopped at $8^h35^m$. No action at farther end of stem. Operated at intervals later. |
| Aug. 22, | 1 | p. m. | Exhaust −740. |
| | 5 | p. m. | Do. −660. Stem −30. |
| Aug. 23, | 8 | a. m. | Do. −628. Stem −35. |
| | 9 30 | a. m. | Do. −742. Stem −35. |
| | 11 15 | a. m. | Do. −640. Stem −28. |
| | 4 30 | p. m. | Do. −500. Stem −22. |
| Aug. 25, | 8 45 | a. m. | Pump started and operated for 15 minutes. No effect at opposite end of stem. |
| | 11 | a. m. | Pump operated for a half hour and stopped with column at −742. At the end of an hour (12 noon) the column at the farther end had been pulled up to 23 mm. |
| | At $3^h30^m$, 4 hours after the exhaust had been left at −742, the column at the end of the stem had risen to 90 mm. at which time the exhaust had fallen to −630 mm | | |
| | At $4^h15^m$ p. m. Exhaust −605, stem −95. Pump operated 5 minutes on exhaust. | | |
| Aug. 26, | 7 45 | a. m. | Exhaust chamber stood at −330 and stem at 60 mm. Pump operated for 40 minutes. |
| | 8 25 | a. m. | Exhaust −742. Stem −57 mm. |
| | 11 30 | a. m. | Do. −660. Stem −45 mm. Pump operated for 5 minutes to bring exhaust to −742. |
| | 7 | p. m. | Exhaust −560. Stem −60 mm. Pump operated for 5 minutes. |
| Aug. 27, | 7 40 | a. m. | Pump operated for 5 minutes as stem suction was at 0 and air was released from end. |
| Aug. 28, | 8 30 | a. m. | Exhaust −200. Stem −90. Pump operated. |
| | 3 30 | p. m. | Do. −555. Stem −85. |
| Aug. 29, | 7 30 | a. m. | Do. −240. Stem −6. |
| Aug. 30, | 10 | a. m. | Pump started after connection had been refitted. Short section taken off and plug again screwed into the center of the stem. |
| | 6 | p. m. | Exhaust −500. Stem −115. Pump operated a few minutes. |
| Aug. 31, | 9 | a. m. | Do. −200. Stem −8. |
| Sept. 1, | 7 | a. m. | Do. −200. Stem −40. |
| | 10 30 | a. m. | Do. −200. Stem −8. Pump operated. |
| Sept. 2, | 7 30 | a. m. | Do. −300. Stem −180. Pump operated. |
| | 11 | a. m. | Do. −660. Stem −140. |

Suction applied to bores made in the 3 or 4 outer layers of a stem of the Monterey pine, the free end of which is immersed in liquid, results in extraction of sap solutions from these layers, and also greatly accelerates the movements of dyes introduced into the free ends. The rates of movement were seen to vary in the pine from 35 to 96 cm. per hour under suction less than an atmosphere. These rates suggest the possibility of much higher rates of movement from tensions of several atmospheres which might be set up in the menisci of transpiring cells in the leaves.

Bore-holes or stumps, in which the inner gas-filled wood is placed in condition to absorb water, invariably show suction which may not be due to less than atmospheric pressures in this wood. Capillary action of conduits and the slower passage of water into tracheids would set up "negative pressures," sometimes misinterpreted.

When one end of a stem is connected with a manometer, suction is generally registered at once. A similar fitting at the other end of the stem connected with an air pump gives opportunity to test longitudinal transmission of suction.

The application of suction to bore-holes in selected layers at measured distances from other bores allows the tangential or circumferential transmission to be measured. It was found that the absorption or suction was not transmitted to half the circumference, of a small trunk, and in fact that the maximum action of a pump holding up a column of Hg. 740 mm. in height did not show on a manometer attached to bores more than 10 mm. distant tangentially.

Transmission of suction applied to the entire surface of the end of a small trunk was marked in lengths of 3 meters, and presented certain features identifiable with the resistance offered by the older wood. Thus a suction that would hold up over 740 mm. mercury when transmitted through a stem nearly 2 meters in length held up a column of 520 mm. in a vertical tube connected with a sheathing hose at the further end, in one instance, and sustained more than 400 mm. in many other cases. Another noticeable feature was the manner in which, as the suction fell at one end after stoppage of the pump, it would continue to rise at the other, as shown by the manometer.

## SUCTION FORCE IN TRUNK OF MONTEREY PINE KILLED BY DEFOLIATION.

Although the view held by some writers that the living cells of stems exercise a pumping or pulsatory action on the upward movement has not found adequate support, many workers assume that the ascent of sap can not take place except by the intervention of living cells. It has been proved at various times that water may enter dead shoots through a dead root-system, that the ascending column may pass through sections of stem that have been killed, but the workers who accept the explanation of Dixon as to the mechanism of the moving water-column under tensions set up by loss of water from the menisci in the leaves hold with him that the presence of living cells is necessary for the maintenance of the sap-column. While the sap-column is undoubtedly affected by the action of the living cells in the root, by the parenchymatous cells of the xylem of the rays, and while the suction force creating the tensions ordinarily originate in the walls of living cells, I have shown that elementary colloidal conditions rather than any complex of living material constituted the sine qua non of the ascent of sap.

This is based upon the results of tests made with small trees (6 to 8 meters in height) which have died several weeks after defoliation. The leaves were removed by being pulled directly from their sheaths, the scar being quickly sealed by resinous excretions. The Monterey pine perishes if older leaves are removed in such manner that only new undeveloped or no leaves remain, as I have previously described.[1] The matter may be illustrated by the completed history of Pine No. 27, of which some description has been made in the publication mentioned.

[1] MacDougal, D. T. Reversible variations in volume, pressure, and movements of sap in trees. Publ. No. 365, 1925. (See pp. 67–85.)

This tree had been defoliated in January 1924, leaving only the terminal tufts of very young leaves. It had been noted late in November that nearly all of these tufts were brownish and dead. Despite this fact some reversible variations occurred, and a warm rain on January 13 was followed by a notable increase in diameter. One tuft was noted which retained a greenish tinge. It is important to determine whether or not any reversible variation occurred after all of the living cells had perished.

A manometer fitted to a tangential bore-hole in September 1924 showed suction by which the air-column in a manometer was extended from 63 to 68 mm., which was equivalent to 0.08 atmospheres, or about 61 mm. Hg.

A month later a similar fitting showed an exudation pressure compressing an air-column from 95 to 92 mm. and increase of 0.03 atmospheres. A repetition of the test showed only suction.

On January 16, 1925, a closer examination of these leaves revealed the fact that the young shoots on which they were borne were entirely dead and all of the cells were brown. The leaves were also dead and fell off as touched. The dendrograph was continued on the trunk and recorded reversible variations in diameter of a range of about 0.2 mm., and, as the diameter of the trunk was 75 mm., it is to be seen that the coefficient was 1 in 375, which was not widely different from that of other small uninjured trees at the same time.

Six months later, when the brownish granular condition of the tips, the leaves, and all material external to the woody cylinder, made it obvious that the tree was dead, the dendrograph bearings were cleaned, and arrangements were made to connect a manometer with a tangential bore 50 cm. in depth in the wood, 35 cm. from the base. A brass tube was screwed into place, sealed and connected with an open-arm manometer, the leading tube being filled with water. Suction pressures in terms of mm. Hg. were recorded as follows (Table 17):

The tree was dead at the time these observations were begun, yet showed two phases of action which are apparently inseparable from a continuous mesh or column in wood-cells, viz, daily reversible variations in the diameter of the trunk and suction of a type indicating that the bore penetrated both layers conducting water and others filled with gases. At the end the trunk being progressively desiccated, and the column attenuated, it was finally broken. This stoppage was coincident with the work of beetles and with a condition of low soil moisture.

TABLE 17.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| June 4 | $3^h05^m$ p. m. | − 0 | Clear. |
| | 3 08 p. m. | − 8 | |
| | 3 10 p. m. | −12 | |
| | 3 35 p. m. | −25 | |
| | 3 55 p. m. | −35 | |
| June 5 | 4 p. m. | −34 | Reset to 0. |
| June 6 | 7 a. m. | −35 | |
| | 4 p. m. | −35 | Reset to 0; clear and warm. |
| June 7 | 8 a. m. | −34 | |
| June 8 | 7 a. m. | −32 | Heavy fog. |
| | 2 p. m. | −30 | |
| June 9 | 7 a. m. | −30 | Clear. |
| | 10 30 a. m. | −25 | Do. |
| June 10 | 7 a. m. | −25 | Reset; clearing. |
| | 3 30 p. m. | −21 | Clear. |
| June 11 | 8 a. m. | −27 | Cloudy. |
| | 3 p. m. | −18 | Clear. |
| June 12 | 7 a. m. | −25 | Do. |
| | 3 p. m. | −30 | Cloudy. |
| June 13 | 7 a. m. | −36 | Reset to 0. |
| | 9 a. m. | − 2 | Stopcock opened. |
| | 4 p. m. | ......... | Stopcock closed. |
| June 14 | 8 a. m. | −28 | Cloudy, and has been for 2 days. |
| June 15 | 8 a. m. | −33 | Cloudy. |
| | 2 p. m. | −16 | Clear. |
| June 16 | 8 a. m. | −35 | Cloudy. |
| | 4 p. m. | −37 | Do. |
| June 17 | 9 a. m. | −40 | Do. |
| | 12 m. | −33 | Do. |
| | 4 p. m. | −35 | Do. |
| June 18 | 3 p. m. | −34 | Cloudy; reset. |
| June 19 | 7 a. m. | −28 | Clear. |
| | 11 30 a. m. | −28 | Clouding. |
| | 2 30 p. m. | −24 | Clearing. |
| June 20 | 8 a. m. | −33 | Fog. |
| June 20 | 12 m. | −33 | Fog. |
| | 4 p. m. | − 0 | Do. |
| June 21 | 8 a. m. | −30 | Do. |
| | 12 m. | −29 | Do. |
| June 22 | 7 a. m. | −33 | Clearing. |
| | 10 a. m. | −26 | Clear. |
| | 4 p. m. | −16 | Do. |
| June 23 | 8 a. m. | ......... | |
| June 24 | 7 a. m. | −30 | Clear. |
| | 11 a. m. | −27 | Do. |
| | 2 p. m. | −16 | Do. |
| June 25 | 7 a. m. | −31 | Do. |
| | 12 m. | −30 | Do. |
| | 4 p. m. | −34 | Do. |
| June 26 | 7 a. m. | −32 | Do. |
| | 4 30 p. m. | −33 | Do. |
| June 27 | 8 a. m. | −34 | Cloudy. |
| | 3 p. m. | −33 | Reset; cloudy. |
| June 28 | 8 a. m. | −22 | Cloudy. |
| | 4 p. m. | −24 | Warm and brighter. |
| July 5 | 8 30 a. m. | −32 | Overcast. |
| July 8 | 7 30 a. m. | −34 | |
| July 12 | 10 30 a. m. | − 0 | Clear. |
| July 13 | 7 30 a. m. | − 0 | Do. |
| | 3 30 p. m. | − 1 | Tube freshly sealed to bore-hole. Stems showing perforations by borers. |
| July 14 | 7 30 a. m. | ......... | Action ceased. |

## CARBOHYDRATES IN SAP OF MONTEREY PINE.

Earlier determinations based on extraction from splints gave marked differences between the newest wood and the layers beneath, carrying the sap steam.[1]

The perfection of the method by which sap was sucked from the separate layers gave better opportunity for determinations of the sugars as glucose by the picric-acid reduction method, as it had been previously used on the earlier samples.

On June 24 sap drawn from the current layer of wood contained 0.27 gram per liter of sugar, and had an acidity denoted by pH 5.6. Sap from the second and third layers showed a sugar content of 0.16 gram per liter, and pH 5.4. The same layers after continued extraction furnished a sample with a sugar content of 0.13 gram per liter with pH 5.5.

Another section of the same trunk examined 2 days later yielded 0.2 gram per liter at pH 5.4 from the outer layer, while sap from the second layer showed only 0.05 gram per liter at pH 5.6, and sap from the third layer 0.07 gram per liter. Sap from the fourth layer had a sugar content of 0.06 gram per liter with an acidity denoted by pH 5.4 On July 2, a sample taken from the outermost layer of a small tree showed 0.49 gram per liter and pH 5.6. On July 13 and July 14 samples of sap taken from the second and third layers of a small tree showed a sugar content of 0.28 to 0.30 gram per liter at pH 5.4, while two samples sucked from the outermost layer had a sugar-content of only 0.17 gram per liter at pH 5 and 5.1.

The low sugar concentration in the outermost layer, which is the striking feature of the last instance, may be connected with the fact that this layer is of a recently formed internode in which dye solutions move upward with greater facility than they do in wood internal to this layer.

Five days after the tree was cut a section of the upper end was removed, new bores were made, and extracts taken from the outer layer of the lower part of trunk. The sap of the outer layer had a sugar content of 0.14 gram per liter and an acidity denoted by pH 6.8, while the sap of inner layers had a sugar content of 0.12 per liter and an acidity of pH 5.7.

These meager results illustrate the fact that the concentration of sugar in the outermost layer is generally markedly different from that of the inner wood. The proportion of sugar is invariably least in layers in which strong upward movements of dye take place. In accordance with this idea, sugar is most concentrated in the outer layer of the lower part of the trunk, and least so in the terminal internodes.

[1] MacDougal, D. T. Reversible variations in volume, pressure, and movements of sap in trees. Publ. No. 365, Carnegie Inst. Wash., 1925. (See pp. 30, 31, 77, 78.)

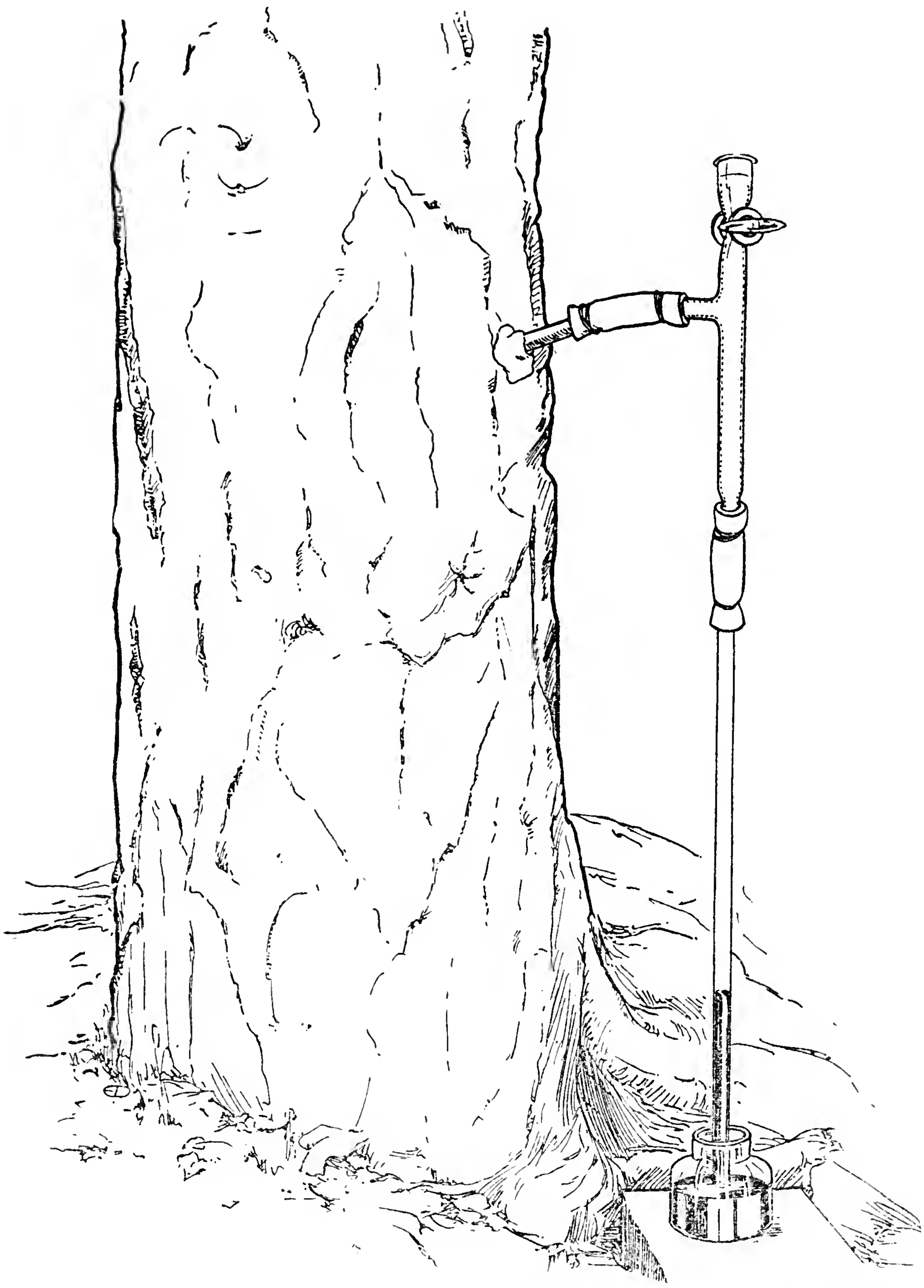

Fig. 17.—Manometer with vertical arm standing in a dish of mercury, attached to a tangential bore in an oak tree. Suction =0.5 atm. was registered.

The highest concentration of sugar was found by extraction from cross-section of the stem in which communication with the central air-filled wood has been blocked by a screw plug. Such a sample showed 1.2 grams sugar per liter at an acidity of pH 5.6. A sample taken from the second and third layers of a small trunk in mid-August yielded 9.198 grams sugar as glucose, in 6.54 liter of sap. A lower concentration was again found in a sample from the second and third layers of a small trunk taken on October 24, 1925, in which sugar amounted to 0.2 gram per liter with an acidity denoted by pH 5.5.

## SUCTION IN QUERCUS AGRIFOLIA.

For purposes of comparison with the action of the pines one series of measurements of pressures in stems of *Quercus agrifolia* was made. This oak has a bark several centimeters in thickness in which living elements persist for several seasons, and which does not begin to split or flake until the tree has attained considerable age. The rifts then occurring are wide apart. A bore for the attachment of manometers may pass through a layer 5 or 6 cm. full of sap before the woody cylinder is reached.

The bores in this tree were made tangentially for the purpose of engaging the newest wood in which the annually formed layers may be a centimeter in thickness. Any such cavity cuts across numerous large vessels, so that the pressures measured are to be taken as the complex result of the action of the wood carrying the sap stream and of air-filled conduits into which water may pass from the connecting tube of an attached manometer. Operations were as follows:

*May 23, 8 a. m.* A hole 8 mm. in diameter was bored tangentially in a small tree near the laboratory (fig. 17). A section of brass tubing threaded at the end and luted with a thin solution of Canada balsam was screwed in until it engaged the woody layers firmly and could be turned with difficulty. The tube engaged the wood to a depth of 15 mm., and a cavity 4.5 cm. was left free. A manometer with an open arm was attached (fig. 3), to be replaced later by the vertical column shown in figure 17. The stopcock of the manometer was left open to allow absorption of water by the trunk for a few hours. The records are shown in Table 18.

TABLE 18.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| May 23 | $8^h10^m$ a. m. | ......... | 20 ml. water absorbed. |
| | 8 22 a. m. | ......... | 15 ml. water absorbed. |
| | 8 38 a. m. | ......... | 20 ml. water absorbed. |
| | 11 30 a. m. | ......... | 30 ml. water absorbed. After about 100 ml. water had entered the wood, the stopcock was closed and further absorptions were recorded as suction in terms of mm. Hg. |
| | 11 40 a. m. | ......... | Set at 0. |
| | 11 42 a. m. | − 48 | |
| | 11 50 a. m. | − 75 | |
| May 24 | 9 10 a. m. | ......... | Open from previous record. Set at 0. |
| | 10 a. m. | − 20 | |
| | 10 30 a. m. | − 38 | |
| May 25 | 8 a. m. | − 12 | |
| | 4 p. m. | − 12 | |
| May 26 | 8 a. m. | − 12 | Cloudy. |
| | 11 30 a. m. | − 11 | Sunny. |
| May 27 | 9 a. m. | − 12 | |
| | 3 p. m. | − 12 | |
| May 28 | 8 a. m. | − 12 | |
| May 30 | 12 m. | ......... | Reset at 0. |
| | 2 p. m. | − 12 | |
| | 4 p. m. | − 12 | |
| May 31 | 8 30 a. m. | − 12 | Raining. |
| | 11 a. m. | − 15 | Clearing. |
| | 5 30 p. m. | − 20 | |
| June 1 | 7 a. m. | − 20 | Reset at 0; raining. |
| | 4 p. m. | − 18 | Clear. |
| June 2 | 8 a. m. | − 26 | Raining. |
| | 12 m. | − 36 | Cloudy. |
| | 4 p. m. | − 50 | Raining. |
| June 3 | 8 a. m. | − 55 | Clearing. |
| | 4 p. m. | − 74 | Clear. |
| June 4 | 8 a. m. | − 78 | Clear. |
| | 11 30 a. m. | − 80 | Do. |
| | 3 30 p. m. | − 77 | Do. |
| June 5 | 7 a. m. | − 44 | Raining. |
| | 4 p. m. | − 60 | |
| June 6 | 7 a. m. | − 65 | Cloudy. |
| | 4 p. m. | − 58 | Clear. |
| June 7 | 8 a. m. | − 48 | |
| June 8 | 7 a. m. | − 30 | |
| | 2 p. m. | − 32 | |
| June 9 | 7 a. m. | − 55 | Clear. Reset; a large air-bubble released. |
| | 7 30 a. m. | ......... | |
| | 8 10 a. m. | − 5 | |
| | 10 30 a. m. | − 6 | |
| June 10 | 3 30 p. m. | − 10 | |
| June 11 | 8 a. m. | − 6 | Cloudy. |
| | 3 p. m. | − 11 | Clear. |
| June 12 | 7 a. m. | − 17 | Do. |
| | 3 p. m. | − 36 | Cloudy. |
| June 13 | 7 a. m. | − 44 | Do. |
| | 9 a. m. | − 52 | Do. |
| | 4 p. m. | − 65 | Do. |
| June 14 | 8 a. m. | − 80 | Do. |
| | 9 a. m. | − 80 | Do. |
| June 15 | 8 a. m. | −112 | Do. |
| | 2 p. m. | − 70 | Clear. Air; reset to 0. |
| June 16 | 8 a. m. | − 2 | Cloudy. |
| | 4 p. m. | − 9 | Do. |

TABLE 18.—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| June 17 | 9h m a. m. | − 10 | Cloudy. |
| | 12 m. | − 11 | Do. |
| | 4 p. m. | − 20 | Do. |
| June 18 | 3 p. m. | − 32 | Do. |
| June 19 | 7 a. m. | − 39 | Clear. |
| | 9 30 a. m. | − 42 | Do. |
| | 11 30 a. m. | − 53 | Clouding. |
| | 2 30 p. m. | − 60 | Clearing. |
| June 20 | 8 a. m. | − 75 | Fog. |
| | 12 m. | − 70 | Do. |
| | 4 p. m. | − 83 | Do. |
| June 21 | 8 a. m. | − 96 | Do. |
| | 12 m. | − 98 | Do. |
| June 22 | 7 a. m. | −122 | Clearing. |
| | 8 30 a. m. | −132 | Clear. |
| | 10 a. m. | −134 | Do. |
| | 4 p. m. | −141 | Do. |
| June 23 | 8 a. m. | −139 | Do. |
| | 10 30 a. m. | −120 | Do. |
| June 24 | 7 a. m. | −168 | Do. |
| | 11 a. m. | −168 | Do. |
| | 2 p. m. | 204 | Manometer replaced by vertical column (fig. 15). |
| June 25 | 7 a. m. | − 23 | Clear. |
| | 12 m. | − 70 | Do. |
| | 4 p. m. | −102 | Do. |
| June 26 | 7 a. m. | −115 | Do. |
| | 4 30 p. m. | −190 | Do. |
| June 27 | 8 a. m. | −175 | Cloudy. |
| | 3 p. m. | −185 | Do. |
| June 28 | 8 a. m. | −182 | Cloudy. |
| | 4 p. m. | −208 | Do. |
| June 29 | 9 a. m. | −200 | Do. |
| | 4 p. m. | −215 | Do. |
| June 30 | 7 a. m. | −200 | Clear. Air bubble released; reset to −200. |
| | 2 p. m. | −235 | Clear. |
| July 1 | 7 a. m. | −215 | Do. |
| | 8 a. m. | −220 | Do. |
| | 9 a. m. | −221 | Do. |
| | 10 a. m. | −225 | Do. |
| | 11 a. m. | −236 | Do. |
| | 12 m. | −235 | Do. |
| | 3 p. m. | −245 | Fog. |
| | 4 30 p. m. | −246 | Do. |
| | 8 p. m. | −245 | Do. |
| July 2 | 7 a. m. | −233 | Do. |
| | 8 a. m. | −225 | Fog and drizzle; air released; reset to −170. |
| | 9 30 p. m. | ......... | Air released; reset to −160. |
| | 11 a. m. | −158 | Misty. |
| | 7 p. m. | −168 | Do. |
| July 3 | 7 a. m. | −177 | Do. |
| | 8 30 a. m. | −160 | Do. |
| | 11 30 a. m. | −165 | Clearing. |
| | 2 30 p. m. | −175 | Do. |
| | 5 p. m. | −185 | Fog. |
| July 4 | 9 a. m. | −176 | Do. |
| | 11 a. m. | −180 | Clear. |
| | 3 30 a. m. | −240 | Do. |
| July 5 | 8 30 a. m. | −196 | Overcast. |
| | 10 30 a. m. | −200 | Clear. |
| | 4 30 p. m. | −234 | Do. |

TABLE 18.—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 6 | 7h m a. m. | −246 | Clear. |
| | 11 a. m. | ......... | Air released; reset at −190. |
| | 6 30 p. m. | −246 | Clear. |
| July 7 | 7 a. m. | −220 | Do. |
| | 9 a. m. | −220 | Do. |
| | 2 p. m. | −228 | Do. |
| | 4 p. m. | −238 | Do. |
| July 8 | 7 30 a. m. | −220 | Large air bubble released; set to −224. |
| | 9 30 a. m. | −224 | Clearing. |
| | 2 p. m. | −262 | Clearing. Air in tube released, reset to −258. |
| | 4 p. m. | −268 | Overcast. |
| July 9 | 7 30 a. m. | −233 | Fog and drizzle. |
| | 10 30 a. m. | −226 | Do. |
| | 4 p. m. | −235 | Overcast. |
| July 11 | 7 30 a. m. | −218 | Clear. |
| | 11 a. m. | −180 | Air out; set at −170. Clear. |
| | 2 30 p. m. | −188 | Clear. |
| | 4 30 p. m. | −250 | Do. |
| July 12 | 8 a. m. | −223 | Do. |
| | 10 30 a. m. | −233 | Do. |
| July 13 | 7 30 a. m. | −243 | Do. |
| | 9 30 a. m. | −254 | Do. |
| | 12 m. | −263 | Do. |
| | 3 30 p. m. | −272 | Air out; reset at −248. |
| July 14 | 7 30 a. m. | −235 | Clear. |
| | 11 30 a. m. | −242 | Clouds. |
| | 2 15 p. m. | −268 | Foggy. |
| July 15 | 7 30 a. m. | −240 | Foggy. |
| | 9 30 a. m. | −238 | Clear. Air released; reset at −235. |
| | 1 30 p. m. | −255 | |
| July 16 | 7 a. m. | −233 | Clear. |
| | 11 a. m. | −236 | Do. |
| | 3 30 p. m. | −260 | Do. |
| July 17 | 7 a. m. | −230 | Do. |
| | 3 15 p. m. | −262 | |
| July 18 | 7 a. m. | −233 | Clouds. Air released and reset to 235. |
| July 19 | 7 40 a. m. | −232 | Air out; reset to −205. |
| | 8 a. m. | −230 | Clouds. |
| | 11 30 a. m. | −250 | |
| | 4 p. m. | −262 | |
| | 5 p. m. | −238 | |
| July 20 | 7 a. m. | −222 | Cloudy. |
| | 11 30 a. m. | −218 | |
| | 3 30 p. m. | −238 | Clear. |
| July 21 | 7 a. m. | −230 | Overcast. |
| | 11 a. m. | −278 | Do. |
| | 4 p. m. | −248 | Clouds. |
| July 22 | 7 a. m. | −238 | Air out; reset at −220. |
| | 4 30 p. m. | −240 | |
| July 23 | 7 40 a. m. | −220 | Overcast. |
| | 11 45 a. m. | −238 | Clear. |
| | 4 p. m. | −260 | Air out; reset at −270. Clear. |
| July 24 | 7 30 a. m. | − 98 | Cloudy. Air released; reset at −200. |
| | 4 p. m. | −222 | Clouds. |
| July 25 | 7 30 a. m. | −220 | Overcast. |
| | 9 a. m. | −226 | Clear. |
| | 12 m. | −220 | Do. |
| | 3 p. m. | −235 | Clouds. |
| July 26 | 7 30 a. m. | −218 | Fog. Air released; reset at −210. |
| | 10 a. m. | −208 | Overcast. |
| | 3 p. m. | −225 | Do. |

TABLE 18.—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| July 27 | $7^h30^m$ a. m. | −206 | Overcast. |
| | 11 30 a. m. | −205 | Do. |
| | 2 30 p. m. | −210 | Do. |
| July 28 | 7 a. m. | −202 | Overcast. Air released; reset at −210. |
| | 11 a. m. | ......... | Reset at −200. |
| | 2 p. m. | −170 | |
| July 29 | 7 40 a. m. | ......... | Instrument leaking at stopcocks. |
| July 31 | 7 30 a. m. | ......... | Refitted and reset at −180. |
| | 11 30 a. m. | −176 | Sunny. |
| Aug. 2 | 3 45 p. m. | −175 | Do. |
| Aug. 3 | 7 30 a. m. | −178 | Overcast. |
| | 11 30 a. m. | −176 | Sunshine. |
| | 3 40 p. m. | −177 | Do. |
| Aug. 4 | 8 a. m. | −175 | Overcast. |
| | 2 30 p. m. | −175 | Sunny. |
| Aug. 5 | 9 a. m. | −176 | Fog. |
| Aug. 6 | 2 30 p. m. | −171 | Sunshine. |
| Aug. 7 | 9 a. m. | −173 | Fog. |
| | 4 p. m. | −170 | Sunny. Opened to absorb water. |
| Aug. 8 | 4 p. m. | ......... | 2.8 ml. absorbed. |
| Aug. 9 | 7 p. m. | ......... | 2.5 ml. absorbed. |
| Aug. 10 | 4 p. m. | ......... | 2. Stopcocks closed and column set to −170. |
| Aug. 11 | 8 a. m. | −223 | Clear. |
| | 11 30 a. m. | −240 | Do. |
| | 7 p. m. | −272 | Do. |
| Aug. 12 | 7 30 a. m. | −260 | Do. |
| | 11 30 a. m. | −270 | Do. |
| | 4 15 p. m. | −303 | Do. |
| Aug. 13 | 7 30 a. m. | −288 | Overcast. |
| | 11 30 a. m. | −290 | Do. |
| | 7 p. m. | −318 | Clear afternoon. |
| Aug. 14 | 5 45 a. m. | −305 | Overcast. |
| | 8 45 a. m. | −300 | Clearing. |
| Aug. 15 | 11 a. m. | −307 | Overcast. Air released; reset at −295. |
| Aug. 16 | 7 30 a. m. | −290 | Do. |
| | 4 p. m. | −305 | Do. |
| Aug. 17 | 7 30 a. m. | −295 | Do. |
| | 11 30 a. m. | −302 | Clear at $9^h30^m$. |
| | 4 30 p. m. | −320 | Do. |
| Aug. 18 | 7 30 a. m. | −340 | Do. |
| | 11 a. m. | −305 | Air out; reset at −308. |
| | 4 p. m. | −325 | |
| Aug. 19 | 7 a. m. | −358 | Clear. |
| | 11 45 a. m. | −320 | Do. |
| | 4 15 p. m. | −380 | Do. |
| Aug. 20 | 7 30 a. m. | −314 | Overcast. |
| | 11 30 a. m. | −343 | Clear. |
| Aug. 21 | 3 30 p. m. | −325 | Do. |
| Aug. 22 | 8 a. m. | −317 | Do. |
| | 11 30 a. m. | −320 | Do. |
| | 5 p. m. | −333 | Do. |
| Aug. 23 | 8 a. m. | −325 | Misting. |
| | 11 15 a. m. | −323 | Clearing. |
| | 4 30 p. m. | −328 | Air out; reset at −308. |
| Aug. 24 | 7 30 a. m. | −310 | Column fell 10 mm. to this point on shaking slightly. Clear. |
| | 11 30 a. m. | −318 | Clear. |
| | 4 p. m. | −332 | Do. |
| Aug. 25 | 7 30 a. m. | −333 | Do. |
| | 11 30 a. m. | −333 | Do. |
| | 4 p. m. | −338 | Do. |

TABLE 18.—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Aug. 26 | $8^h$ $^m$ a. m. | −321 | Air released; reset at −307. Overcast. |
| | 11 30 a. m. | −297 | Beginning to clear. |
| | 7 15 p. m. | −305 | Overcast. |
| Aug. 27 | 6 a. m. | −293 | |
| | 7 a. m. | −292 | |
| | 8 a. m. | −289 | |
| | 9 a. m. | −288 | |
| | 10 a. m. | −288 | |
| | 12 m. | −296 | |
| | 2 p. m. | −299 | |
| | 3 p. m. | −302 | |
| | 4 p. m. | −303 | |
| | 5 p. m. | −304 | |
| | 8 p. m. | −304 | |
| | 11 p. m. | −300 | |
| Aug. 28 | 3 a. m. | −299 | |
| | 4 a. m. | −298 | |
| | 6 a. m. | −297 | |
| | 8 a. m. | −296 | |
| | 9 a. m. | −294 | |
| | 10 a. m. | −295 | |
| | 11 a. m. | −296 | |
| | 2 p. m. | −301 | |
| | 4 p. m. | −304 | |
| | 7 p. m. | −308 | |
| | 9 p. m. | −306 | |
| Aug. 29 | 3 a. m. | −304 | |
| | 4 a. m. | −302 | |
| | 6 a. m. | −304 | |
| | 8 a. m. | −297 | |
| Aug. 30 | 9 a. m. | −289 | Air released; reset at −290. |
| | 10 a. m. | −290 | |
| | 12 m. | −280 | Clear. |
| | 6 p. m. | −282 | Do. |
| Aug. 31 | 9 a. m. | −275 | Overcast. |
| | 4 p. m. | −287 | Do. |
| Sept. 1 | 7 a. m. | ......... | |
| | 12 m. | −288 | Clear. |
| | 7 p. m. | −297 | Do. |
| Sept. 2 | 7 a. m. | −296 | |
| | 11 a. m. | −295 | |
| Sept. 5 | 11 a. m. | −300 | |
| | 6 30 p. m. | −308 | |
| Sept. 6 | 8 30 a. m. | −301 | Clearing. |
| | 6 p. m. | −297 | Clouds. |
| Sept. 7 | 7 30 a. m. | −298 | Clear. |
| | 11 15 a. m. | −293 | Do. |
| | 4 15 p. m. | −297 | |
| Sept. 8 | 7 30 a. m. | −297 | Do. |
| | 11 30 a. m. | −288 | Do. |
| | 4 p. m. | −293 | |
| Sept. 9 | 8 a. m. | −295 | Cloudy. |
| | 11 30 a. m. | −293 | Clear. |
| Sept. 10 | 7 30 a. m. | −287 | Cloudy. |
| Sept. 13 | 8 a. m. | −263 | Air released and reset at −340. |
| | 6 p. m. | −333 | Clear. |
| Sept. 14 | 7 15 a. m. | −333 | Do. |
| | 11 30 a. m. | −322 | Do. |
| | 4 p. m. | −317 | Do. |
| Sept. 15 | 7 15 a. m. | −293 | Do. |
| | 3 30 p. m. | −282 | Do. |

TABLE 18.—*Continued.*

| Date. | Time. | | Suction in mm. Hg. | Remarks. |
|---|---|---|---|---|
| 1925 | | | | |
| Sept. 16 | $7^h30^m$ | a. m. | −256 | Clouds. |
| Sept. 18 | 7 | a. m. | −200 | Clouds; rain on Sept. 17. |
| Sept. 20 | 9 | a. m. | −193 | Clear. |
| Sept. 21 | 7 30 | a. m. | −195 | Do. |
| | 11 30 | a. m. | −193 | Do. |
| | 4 | p. m. | −188 | Clear. |
| | 5 | p. m. | ......... | |
| Sept. 22 | 7 30 | a. m. | −193 | Do. |
| | 11 30 | a. m. | −189 | Do. |
| | 5 30 | p. m. | −191 | Cloudy. |
| Sept. 23 | 8 | a. m. | −197 | Do. |
| | 12 | m. | −190 | |
| | 4 | p. m. | −187 | |
| Sept. 24 | 7 15 | a. m. | −195 | Overcast. |
| | 11 30 | a. m. | −184 | Clearing. |
| | 4 | p. m. | −182 | Clouds. |
| Sept. 25 | 8 | a. m. | −183 | Clear. |
| | 5 | p. m. | −178 | Do. |
| Sept. 26 | 7 15 | a. m. | −186 | Do. |
| | 11 45 | a. m. | −178 | Do. |
| | 4 | p. m. | −174 | |
| Sept. 28 | 7 30 | a. m. | −178 | Some clouds. |
| Sept. 29 | 9 45 | a. m. | −183 | Clear. |
| Sept. 30 | 4 | p. m. | −167 | Do. |
| Oct. 4 | 9 | a. m. | −160 | Do. |
| | 4 | p. m. | −158 | Do. |
| Oct. 5 | 7 30 | a. m. | −172 | Clear. Fittings imperfect. Apparatus dismounted, cleaned and refitted; column reset at −227. |
| Oct. 8 | 11 | a. m. | −183 | No air in tube. |
| | 4 | p. m. | −175 | Clear. |
| Oct. 9 | 7 30 | a. m. | −177 | Cloudy. |
| | 3 30 | p. m. | −165 | Do. |
| Oct. 10 | 8 | a. m. | −150 | Do. |
| | 12 | m. | −144 | Overcast. |
| | 4 | p. m. | −138 | Do. |
| Oct. 11 | 8 15 | a. m. | −120 | No air drawn in by this drop from −183. |
| Oct. 12 | 8 | a. m. | −102 | Rainy since noon of Oct. 11. |
| | 4 | p. m. | − 95 | Clouds. |
| Oct. 13 | 8 | a. m. | − 97 | Clear. |
| | 2 | p. m. | − 85 | |
| Oct. 14 | 8 | a. m. | − 86 | Do. |
| Oct. 16 | 9 | a. m. | − 67 | |
| | 4 | p. m. | − 64 | |
| Oct. 17 | 8 | a. m. | − 62 | |
| Oct. 18 | 9 | a. m. | − 63 | |
| Oct. 19 | 8 | a. m. | − 63 | |
| | 4 | p. m. | − 56 | |
| Oct. 20 | 9 | a. m. | − 72 | |
| | 2 | p. m. | − 65 | |
| Oct. 21 | 8 | a. m. | − 80 | |
| Oct. 22 | 4 | p. m. | − 93 | |
| Oct. 23 | 7 | a. m. | −102 | |
| | 11 | a. m. | − 99 | |
| Oct. 24 | 7 | a. m. | −108 | |
| | 12 | m. | −106 | |
| | 7 | p. m. | −100 | |
| Oct. 25 | 8 | a. m. | −110 | Clear. |
| Oct. 26 | 7 30 | a. m. | −210 | Do. |
| Oct. 27 | 8 | a. m. | −133 | Overcast. |
| | 4 | p. m. | −126 | Clear. |

TABLE 18.—*Continued.*

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Oct. 28 | $7^h30^m$ a. m. | −136 | Overcast. |
| | 4 p. m. | −133 | Do. |
| Oct. 29 | 2 p. m. | −133 | Clear. |
| Oct. 30 | 7 30 a. m. | −142 | Overcast. |
| Oct. 31 | 8 a. m. | −143 | Do. |
| Nov. 1 | 10 30 a. m. | −151 | Do. |
| Nov. 2 | 8 a. m. | −158 | Showers. |
| Nov. 3 | 9 a. m. | −165 | Clearing. |
| Nov. 4 | 8 a. m. | −156 | Clear. |
| | 4 p. m. | −148 | Do. |
| Nov. 5 | 8 a. m. | −155 | Do. |
| | 4 p. m. | −146 | Do. |
| Nov. 6 | 8 a. m. | −154 | Do. |
| | 3 p. m. | −142 | No air had been drawn out accompanying lessened suction from Oct. 8–20, when suction began to increase. |
| Nov. 7 | 8 a. m. | −147 | |
| Nov. 8 | 10 a. m. | −134 | |
| Nov. 9 | 8 a. m. | −137 | Clear. |
| | 3 p. m. | −128 | Cloudy. |
| Nov. 10 | 4 p. m. | −124 | Do. |
| Nov. 11 | 7 30 a. m. | −123 | Raining. |
| | 4 p. m. | −118 | Do. |
| Nov. 12 | 8 a. m. | −120 | Cloudy. |
| | 4 p. m. | −110 | Raining. |
| Nov. 13 | 7 30 a. m. | −114 | Clear. |
| Nov. 14 | 7 30 a. m. | −128 | Do. |
| | 4 p. m. | −104 | Do. |
| Nov. 15 | 8 a. m. | −110 | Do. |
| | 1 30 p. m. | − 96 | Do. |
| | 4 p. m. | −101 | Cloudy. |
| Nov. 16 | 8 a. m. | − 97 | Drizzle. |
| Nov. 17 | 7 30 a. m. | − 99 | Clear. |
| Nov. 18 | 7 30 a. m. | − 96 | Do. |
| | 11 30 a. m. | − 93 | Do. |
| | 2 p. m. | − 84 | Do. |
| | 7 p. m. | − 90 | Do. |
| Nov. 19 | 7 30 a. m. | − 91 | Do. |
| Nov. 20 | 8 a. m. | − 95 | Do. |
| | 11 30 a. m. | − 82 | Do. |
| | 2 p. m. | − 79 | Do. |
| | 4 30 p. m. | − 86 | Do. |
| Nov. 21 | 8 a. m. | − 97 | Overcast. |
| | 12 m. | − 88 | Slightly overcast. |
| | 4 p. m. | − 88 | Overcast. |
| Nov. 22 | 8 a. m. | −105 | Clear. |
| Nov. 23 | 7 30 a. m. | − 99 | Overcast. |
| Nov. 24 | 7 30 a. m. | −105 | Do. |
| | 2 p. m. | −100 | Clear. |
| Nov. 25 | 7 a. m. | −121 | Do. |
| | 2 p. m. | −109 | Hazy. |
| Nov. 26 | 12 m. | −110 | Do. |
| Nov. 27 | 8 a. m. | −127 | Clear. |
| Nov. 28 | 8 a. m. | −128 | Do. |

## SUCTION AND CONDUCTION OF DYE IN SMALL OAK TREE.

The extent of absorption of liquid from a bore-hole in the trunk, and the capillary conduction of such liquid, was tested by experiments with small oak trees, using a solution of acid fuchsin 1–1,000 in water in the cavity.

The first tree tested had a diameter of about 10 cm., and a height of 3 meters. A manometer with open U tube adjusted at 8 a. m. showed a suction of −42 mm. Hg. by $11^{h}20^{m}$ a. m. At 8 a. m. of the following day, the dye had gone down the trunk 60 cm. and upward 90 cm. in the vessels of the third, fourth and fifth layers (fig. 16). About 3 ml. of gas had been displaced and accumulated in the manometer. A similar bore in a second tree, connected with a manometer at once, at $8^{h}20^{m}$ a. m. showed suction of −40 mm. Hg.; by $9^{h}30^{m}$ a. m., with displacement of 3 ml. gas; at 10 a. m. 2 ml. gas had been displaced and a suction of −42 set up, the instrument having been reset to 0. A similar record was made at $11^{h}15^{m}$ a. m. At 4 p. m., suction of −25 mm. was shown with an accumulation of 25 ml. gas. At $4^{h}40^{m}$ p. m. another record of −84 mm. Hg. with displacement of 2 ml. of gas was made. The dye had gone down the trunk 65 cm. and upward 100 cm. by the following morning in a total of 26 hours. A bore in a third small tree yielded the following records:

TABLE 19.

| Date. | Time. | Suction in mm. Hg. | Remarks. |
|---|---|---|---|
| 1925 | | | |
| Sept. 26 | $11^{h}$ $^{m}$ a. m. | ......... | Manometer fitted. |
| | 11 30 a. m. | − 70 | No air. |
| | 3 p. m. | − 42 | 1 ml. air released; reset to 0. |
| | 3 40 p. m. | − 67 | No air. |
| | 4 p. m. | − 86 | Do. |
| Sept. 27 | 7 30 a. m. | − 8 | 15 ml. air released; reset at 0. |
| | 11 a. m. | − 33 | 2 ml.; air released. |
| | 4 p. m. | −102 | 2 ml.; air released; reset to 0. Not read for 2 weeks. |

The bore in this tree cut across a number of large conduits, which must have contained gas as an amount of water estimated at 150 ml. was taken from the bore by capillarity in the first week of the test. In this as in many other preparations suction increased throughout the day, and a progressive increase would follow every release of the column by which it was set at 0. Thus when the column was set at 0 on May 15, it rose irregularly to −204 mm. Hg. = 0.26 atm. on the 24th. Being again reset, suction increased to −225 mm. = 0.28 atm. on June 2. After this time a mid-day decrease of suction was observed, or if a general increase were in progress a slacking off of the rate was noticeable.

Disturbances of the weather, fog, clouds, etc., in which a daily rise in temperature was modified, would be followed by deviations from

this program in which changes in volume of included gases was the determining factor. Gases were drawn out in much greater quantity than in the walnut or pine. The maxima of suction observed increased until August 20, when a reading of −380 mm. Hg. = 0.5 atm. was made. Deducting a fraction for capillary action this may be

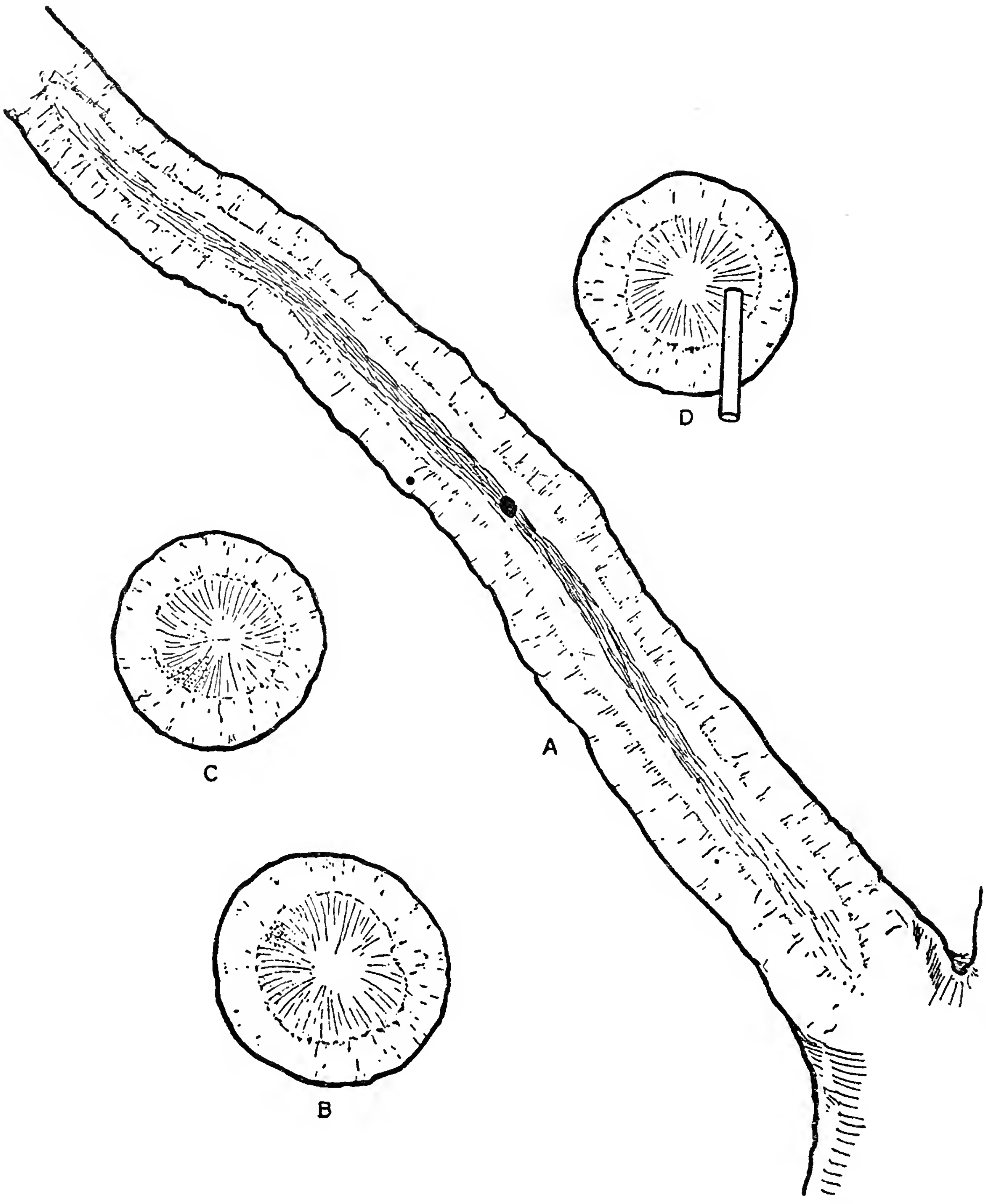


Fig. 18.—Diagrams of longitudinal and cross sections of small oak tree (*Quercus agrifolia*) showing capillary conduction of dye from a tangential bore. D, penetration of bore; A, conduction of dye downward and upward in trunk shown by shading. Stained wood near bore and above it shown by shading in cross-sections B and C.

taken as an index of pressure in the included gases notably less than atmospheric, and as the extreme in the season's observations.

After a period of suction little below the maximum, a diminution followed, so that during the latter half of November suction varied below and above −100 mm. Hg.

TABLE 20.

| Date. | Time. | Suction in mm. Hg. | Date. | Time. | Suction in mm. Hg. |
|---|---|---|---|---|---|
| 1925 | | | 1925 | | |
| Oct. 11 | 8h00m a. m.[1] | −108 | Oct. 24 | 7h m p. m. | −222 |
| Oct. 12 | 4 p. m. | − 95 | Oct. 25 | 8 a. m. | −228 |
| Oct. 13 | 8 a. m. | − 86 | Oct. 26 | 7 30 a. m. | −148 |
| | 2 p. m. | − 18 | Oct. 27 | 8 a. m. | −138 |
| Oct. 14 | 8 a. m. | − 72 | | 4 p. m. | −122 |
| Oct. 16 | 9 a. m. | −140 | Oct. 28 | 7 30 a. m. | −121 |
| | 4 p. m. | − 35 | Oct. 29 | 2 p. m. | −114 |
| Oct. 17 | 8 a. m. | − 92 | Oct. 30 | 7 30 a. m.[2] | −105 |
| Oct. 18 | 9 a. m. | − 88 | Oct. 31 | 8 a. m. | − 86 |
| Oct. 19 | 8 a. m. | −140 | Nov. 1 | 10 a. m. | − 90 |
| Oct. 20 | 9 a. m. | −177 | Nov. 2 | 8 a. m. | − 96 |
| | 2 p. m. | −186 | Nov. 3 | 9 a. m. | −101 |
| Oct. 21 | 8 a. m. | −204 | Nov. 4 | 8 a. m. | −102 |
| Oct. 22 | 4 p. m. | −204 | | 4 p. m. | − 99 |
| Oct. 23 | 7 a. m. | −220 | Nov. 5 | 8 a. m. | −109 |
| | 11 a. m. | −210 | | 4 p. m. | −106 |
| Oct. 24 | 7 a. m. | −228 | Nov. 6 | 8 a. m.[3] | −111 |
| | 12 m. | −175 | | 4 p. m. | −106 |

[1] 1 ml. air released; reset to 0.
[2] Air released; reset at −65.
[3] No air had been displaced since Oct. 30.

The tree was now taken down. The bore had actually penetrated about 2 cm. radially to within a centimeter of the center. The dye was visible to a distance of only 30 cm. below the cavity and twice as far above it in a sector not noticeably wider than the bore. The larger vessels were plainly filled, while wood cells and living elements enmeshed with them were uncolored. It was plainly obvious that the liquid in the manometer system was continuous with capillary extensions into the larger vessels from which gases had been displaced to the lengths indicated. Wide fluctuations in the suction took place in the month ending November 6, when the experiment was terminated. The maximum was reached during the period of October 21 to 25, when the outer layers of other trees nearby were showing temperatures of 19° to 24° C. in the outer layers. The lower suction force measured October 28 to November 6 was coincidental with measuring stem temperatures as low as 5° C. at 7 to 8 a. m.

Suction is seen to increase during periods in which the temperature of the stem runs higher from day to day with implied increase of water loss, and it would appear that the last-named factor is the one to be connected directly with the force of suction developed.

An analysis of the daily variations, which are generally similar to the variations in suction of the central cylinder of both the pine and the walnut, is not so easily made.

Suction is greatest about the beginning of the daylight period at the time when the trunk has reached the limit of its daily expansion and the outer layers are near the minimum temperature with a mini-

mum rate of water-loss. Suction force now decreases toward midday and begins to rise again late in the afternoon. This is well illustrated by the observations of October 24, on which date suction amounted to 228 mm. Hg. at 7 a. m. with temperature of trunks at 14° C.; fell to 175 mm. at noon, with trunk temperature at 24° C.; and had risen to 222 mm. at 7 p. m. with trunk temperature at 15° C. The decrease in suction may be due in part to expansion of gases in the wood, coupled with the actual contraction of the stem. These factors are mentioned as the only ones the action of which is at all concurrent with the variations in suction.

The extensive series of measurements in the larger oak tree, described in the previous section, was made by instruments attached to bores driven tangentially into the trunk and, therefore, engaging more or less fully with the ascending sap stream, in which other factors would be dominant in the determination of daily variations.

## COMPOSITION OF GASES IN CENTRAL CYLINDER OF TRUNK OF OAK.

The composition of the gases in the central part of tree-trunks is a matter of importance in several ways, and analyses were made of samples from the pine and the walnut. The sample of gases from the oak was taken from a tree about 30 cm. in diameter, standing near the one to which the manometer had been attached for several months. A bore was driven radially into the trunk to depth of 12 cm., a brass tube screwed into the opening and a luting of stiff grease applied. A gas receiver (fig. 16) connected with a column of mercury for exhausting was fitted. The preparation was fitted October 6 at $3^h30^m$ p. m., and the system, put under suction of a column of mercury 300 mm., was arranged to clear it of atmospheric gases. The column was again set as above and about 30 ml. gas drawn out in the first half hour. The suction given above was allowed to act until 9 a. m. the following morning. About 200 ml. gas was drawn out in the intervening 17 hours. This was found by two analyses to have a composition as below: $CO_2$: 3.08 p. ct.; 3.04 p. ct. Oxygen: 17.84 p. ct.; 17.49 p. ct. N: 79.08 p. ct.; 79.47 p. ct.

The receiver was again attached at $10^h30^m$ a. m., and a suction of about 200 mm. Hg. arranged. 22 hours later over 200 ml. gas had been obtained, which had a composition as below: $CO_2$: 3.4 p. ct.; 3.43 p. ct. Oxygen: 14.8 p. ct.; 14.84 p. ct. N: 81.8 p. ct.; 81.73 p. ct.

The residue after titration of oxygen and carbon dioxide was taken as all nitrogen, although it is by no means certain that some slight fraction of carbon monoxide may not be included.

It is to be noted that gases are more easily drawn out of the trunk of the oak with its large vessels than from either the pine or walnut.

## SAP PRESSURES IN JUGLANS MAJOR.

The walnut was selected for the most comprehensive test of sap pressures in comparison with those of the pine. Some measurements made on the trunk of a rapidly growing tree, 16 years old, of *Juglans major* were made in September 1924 in a preliminary way. A tangential bore in the trunk to which a manometer with a closed end had been attached gave the following readings, in which the length of the air-column in the manometer is expressed in mm. (Table 21).

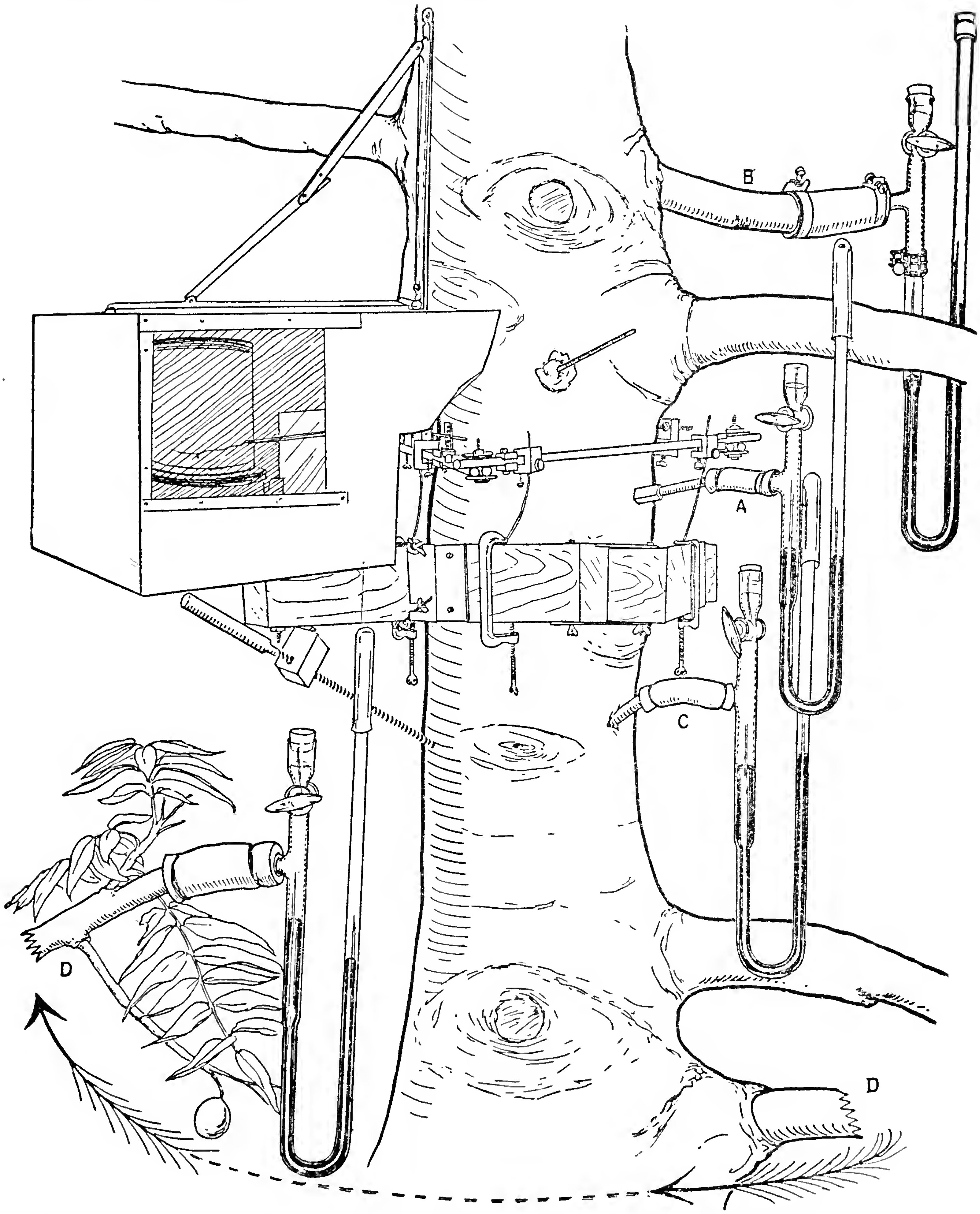


FIG. 19.—Trunk of *Juglans major* with four manometers, a dendrograph and thermometer attached. A, radial bore; B, short stub of branch; C, tangential bore; DD, branch 4 meters in length. Manometers were also attached to cut end of a root and to stump of separated part.

TABLE 21.

| Date. | Time. | Air-column. | Date. | Time. | Air-column. |
|---|---|---|---|---|---|
| | | *mm.* | | | *mm.* |
| 1925 | | | 1925 | | |
| Sept. 24 | $11^h50^m$ a. m. | 67 =0 | Sept. 26 | $2^h$ p. m. | 65 |
| | 12 m. | 72 | Sept. 27 | 4 p. m. | 62 |
| | 12 20 p. m. | 67 | | 9 a. m. | 62 |
| | 3 45 p. m. | 62 | | 10 a. m. | 63 |
| Sept. 25 | 8 a. m. | 62 | | 12 m. | 63 |
| | 11 30 a. m. | 62 | | 2 p. m. | 62 |
| | 2 p. m. | 61 | Sept. 28 | 12 m. | 63 |
| | 4 p. m. | 62 | Sept. 29 | 8 a. m. | 60 |
| Sept. 26 | 8 a. m. | 61 | | 12 m. | 61 |
| | 10 a. m. | 65 | Sept. 30 | 8 a. m. | 60 |
| | 12 m. | 66 | | | |

As soon as the fitting was made some water was taken up by the elements contiguous to the cavity, with the result that suction was recorded, the air-column being elongated from 67 to 72 mm. Soon the reverse process followed, and the air-column was compressed, at the end showing a positive pressure of $\frac{67}{60}$ or 1.1 atmosphere. Early in the following season, while the trunk was in a condition of active enlargement, a tangential bore, 8 cm. in depth, was made in the trunk and fitted with a manometer with open free arm, and a similar instrument was fitted by a clamped pressure hose to the end of a main branch 4 meters in length, which bore several leafy branchlets. The exposed end was 16 mm. in diameter. Later other attachments were made. All readings are given in terms of mm. Hg. Suction being indicated by − and exudation pressure by + (Table 22).

TABLE 22.

| Date. | Time. | Tangential. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|
| 1925 | | | | | |
| May 17 | $9^h05^m$ a. m. | ......... | ......... | − 65 | Fittings made. |
| | 9 35 a. m. | − 8 | ......... | − 80 | |
| | 10 a. m. | − 14 | ......... | − 75 | Air released from both manometers; reset to 0. |
| | 3 30 p. m. | − 3 | ......... | − 10 | |
| May 18 | 8 a. m. | − 3 | ......... | − 10 | |
| May 19 | 3 p. m. | − 3 | ......... | 5 | Air released and both instruments adjusted and reset to 0. |
| May 20 | 8 a. m. | ......... | ......... | ......... | |
| | 3 30 p. m. | − 0 | ......... | − 35 | |
| May 21 | 2 p. m. | − 10 | ......... | − 15 | |
| May 22 | 8 a. m. | − 4 | ......... | − 20 | |
| May 23 | 8 30 a. m. | − 10 | ......... | − 10 | |
| May 24 | 9 a. m. | ......... | ......... | − 10 | Air released from tangential fitting; reset to 0. |
| | 10 a. m. | − 8 | ......... | − 5 | |
| | 10 30 a. m. | − 20 | ......... | ......... | |
| May 25 | 8 a. m. | + 3 | ......... | − 18 | |
| | 4 p. m. | − 37 | ......... | − 30 | |
| May 26 | 8 a. m. | + 17 | ......... | − 30 | Cloudy. |
| | 11 30 a. m. | − 29 | ......... | − 26 | Sunny. |
| May 27 | 9 a. m. | + 17 | ......... | − 37 | Cloudy. |
| | 3 p. m. | − 40 | ......... | − 35 | |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|
| 1925 | | | | | |
| May 28 | $8^{h}$ $^{m}$ a. m. | + 48 | ......... | − 44 | |
| | 11 30 a. m. | − 25 | ......... | − 36 | |
| May 29 | 7 30 a. m. | + 18 | ......... | − 46 | |
| | 4 p. m. | − 30 | ......... | − 42 | |
| May 30 | 8 a. m. | 0 | ......... | − 47 | |
| | 11 a. m. | − 36 | ......... | − 46 | |
| | 2 p. m. | − 37 | ......... | − 47 | |
| | 4 p. m. | − 37 | ......... | − 49 | |
| May 31 | 8 30 a. m. | + 17 | ......... | − 50 | Raining. |
| | 11 a. m. | − 33 | ......... | − 40 | |
| | 5 30 p. m. | 53 | ......... | − 58 | |
| June 1 | 7 a. m. | + 5 | ......... | − 55 | Raining. |
| | 9 a. m. | − 5 | ......... | − 50 | |
| | 4 p. m. | −100 | ......... | − 50 | Clear. |
| June 2 | 8 a. m. | 0 | ......... | − 58 | Raining. |
| | 12 m. | − 47 | ......... | − 55 | |
| | 4 p. m. | − 70 | ......... | − 57 | |
| June 3 | 7 a. m. | − 5 | ......... | − 63 | |
| | 4 p. m. | −110 | ......... | − 60 | Clear. |
| June 4 | 8 a. m. | + 12 | ......... | − 65 | |
| | 11 30 a. m. | − 30 | ......... | − 60 | Clear. |
| | 3 30 p. m. | − 37 | ......... | − 60 | |
| June 5 | 7 a. m. | + 28 | ......... | − 75 | |
| | 4 p. m. | − 72 | ......... | − 65 | Clear. |
| June 6 | 7 a. m. | − 6 | ......... | − 78 | Cloudy. |
| | 4 p. m. | − 32 | ......... | − 65 | |
| June 7 | 8 a. m. | − 8 | ......... | − 70 | Clearing. |
| June 8 | 7 a. m. | − 5 | ......... | − 78 | Heavy fog. |
| | 2 p. m. | − 40 | ......... | − 67 | Clear. |
| June 9 | 7 a. m. | − 5 | ......... | − 78 | |
| | 10 30 a. m. | − 35 | ......... | − 70 | |
| June 10 | 7 a. m. | − 7 | ......... | − 80 | |
| | 3 30 p. m. | − 26 | ......... | − 70 | |
| June 11 | 8 a. m. | − 10 | ......... | − 80 | Cloudy. |
| | 3 p. m. | − 26 | ......... | − 70 | Clear. |
| June 12 | 7 a. m. | − 8 | ......... | − 80 | Air released from tangential bore; reset to 0. |
| | 3 p. m. | − 18 | ......... | − 78 | |
| June 13 | 7 a. m. | − 8 | ......... | − 81 | |
| | 9 a. m. | − 9 | ......... | − 81 | |
| | 4 p. m. | − 48 | ......... | − 78 | |
| June 14 | 8 a. m. | + 10 | ......... | − 81 | Cloudy. |
| | 9 a. m. | + 10 | ......... | − 81 | Do. |
| June 15 | 8 a. m. | + 33 | ......... | − 83 | |
| | 2 p. m. | − 37 | ......... | − 67 | Clear. |
| June 16 | 8 a. m. | + 35 | ......... | − 83 | Do. |
| | 4 p. m. | + 10 | ......... | − 80 | Cloudy. |
| June 17 | 9 a. m. | + 55 | ......... | − 84 | Do. |
| | 12 m. | + 40 | ......... | − 81 | Do. |
| | 4 p. m. | + 12 | ......... | − 79 | Do. |
| June 18 | 3 p. m. | + 18 | ......... | − 78 | Do. |
| June 19 | 7 a. m. | +104 | ......... | − 81 | Clear. |
| | 7 30 a. m. | ......... | − 40 | − 74 | Do. |
| | 8 a. m. | + 76 | − 60 | − 72 | Clear; air released from long branch. |
| | 8 30 a. m. | + 60 | − 70 | − 2 | |
| | 9 30 a. m. | + 35 | − 76 | − 12 | Clouding. |
| | 11 30 a. m. | + 20 | −105 | − 10 | Clearing. |
| | 2 30 p. m. | + 5 | −102 | − 25 | Do. |
| | 5 p. m. | + 4 | − 98 | − 35 | Fog. |
| June 20 | 8 a. m. | +134 | − 96 | − 40 | |
| | 12 m. | + 95 | −103 | − 40 | Fog. |
| June 20 | 4 p. m. | + 54 | 96 | − 40 | Fog. |
| June 21 | 8 a. m. | +134 | ......... | − 45 | Fog; air out; reset to 0 in short stub. |
| | 12 m. | +104 | − 18 | − 48 | Fog. |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|
| 1925 | | | | | |
| June 22 | 7h m a. m. | +152 | − 58 | − 54 | Clearing. |
| | 8 30 a. m. | +148 | − 50 | − 52 | |
| | 10 a. m. | +121 | − 34 | − 52 | Clear. |
| | 4 p. m. | + 10 | − 60 | − 50 | Do. |
| June 23 | 8 a. m. | + 96 | − 16 | − 43 | Do. |
| | 10 30 a. m. | + 37 | − 25 | − 54 | Do. |
| June 24 | 7 a. m. | + 66 | − 72 | − 67 | Do. |
| | 11 a. m. | − 1 | − 63 | − 65 | Do. |
| | 2 p. m. | − 26 | − 75 | − 63 | Do. |
| June 25 | 7 a. m. | + 72 | − 80 | − 62 | Do. |
| | 12 m. | ......... | − 67 | − 72 | Do. |
| | 4 p. m. | − 42 | − 66 | − 69 | Do. |
| June 26 | 7 a. m. | + 86 | − 78 | − 81 | Do. |
| | 4 30 p. m. | − 42 | − 69 | − 66 | Do. |
| June 27 | 8 a. m. | + 78 | − 93 | − 90 | Cloudy. |
| | 3 p. m. | + 54 | − 81 | − 90 | Do. |
| June 28 | 8 a. m. | + 55 | − 84 | − 90 | Do. |
| | 4 p. m. | − 14 | − 74 | − 96 | |
| June 29 | 9 a. m. | + 78 | − 84 | − 97 | Do. |
| | 4 p. m. | + 36 | − 72 | − 96 | Do. |
| June 30 | 7 a. m. | +120 | − 70 | −107 | Clear. |
| | 2 p. m. | + 30 | ......... | − 96 | Air released from tangential bore and short stub. Reset to 0; dendrograph fixed to trunk. |
| July 1 | 7 a. m. | +134 | − 17 | −103 | |
| | 8 a. m. | +120 | − 13 | −102 | |
| | 9 a. m. | +105 | − 9 | − 99 | Clear. |

| Date. | Time. | Tangential. | Temperature. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|---|
| 1925 | | | °C. | | | |
| July 1 | 10h m a. m. | + 84 | ......... | − 0 | −104 | Clear. |
| | 11 a. m. | + 72 | ......... | + 3 | − 99 | Do. |
| | 12 m. | + 54 | ......... | + 3 | − 97 | Do. |
| | 2 p. m. | + 37 | ......... | − 6 | − 98 | Do. |
| | 3 p. m. | + 37 | ......... | − 12 | − 85 | Fog. |
| | 4 30 p. m. | + 43 | ......... | − 17 | −104 | Do. |
| | 8 p. m. | + 75 | ......... | − 26 | −108 | Do. |
| July 2 | 7 a. m. | +158 | ......... | − 26 | −108 | Fog. Bulb of small thermometer inserted into wood of 1924. |
| | 8 a. m. | +160 | ......... | − 24 | −110 | Fog. |
| | 9 30 a. m. | +170 | ......... | − 22 | −108 | Do. |
| | 11 a. m. | +176 | 14 | − 21 | −110 | |
| | 7 p. m. | + 88 | ......... | − 26 | −110 | |
| July 3 | 7 a. m. | +158 | 12.5 | − 28 | −112 | |
| | 8 30 a. m. | +168 | 13 | − 25 | −112 | |
| | 11 30 a. m. | +144 | 16 | − 17 | −108 | Clearing. |
| | 2 30 p. m. | +106 | 18 | − 12 | −112 | Do. |
| | 5 p. m. | + 97 | 17.5 | − 18 | −110 | Do. |
| July 4 | 9 a. m. | + 84 | 15 | − 18 | −113 | |
| | 11 a. m. | + 45 | 19 | − 4 | − 88 | Sunny. |
| | 3 30 p. m. | − 20 | 20 | − 7 | −104 | Do. |
| July 5 | 8 30 a. m. | +112 | 15 | − 22 | −114 | Overcast. |
| | 10 30 a. m. | + 81 | 19 | − 6 | −107 | Clear. |
| | 4 30 p. m. | − 7 | 23 | − 5 | −105 | Do. |
| July 6 | 7 a. m. | +122 | 13 | − 27 | −117 | Do. |
| | 11 a. m. | + 54 | 19 | − 9 | −114 | Do. |
| | 6 30 p. m. | + 14 | 19 | − 21 | −116 | Do. |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Temperature. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|---|
| 1925 | | | °C. | | | |
| July 7 | 7h m a. m. | +126 | 13 | − 33 | −122 | Overcast. |
| | 9 a. m. | +126 | 14.5 | − 30 | −122 | Do. |
| | 2 p. m. | +111 | 20.5 | − 12 | −111 | Clear. |
| | 4 p. m. | + 36 | 22 | − 12 | −103 | Do. |
| July 8 | 7 30 a. m. | +126 | 14 | − 34 | −117 | Overcast. |
| | 9 30 a. m. | +111 | 16.5 | − 22 | −122 | Clearing. |
| | 2 p. m. | + 24 | 20 | − 14 | −117 | Clear. |
| | 4 p. m. | + 14 | 18.5 | − 21 | −122 | Overcast. |
| July 9 | 7 30 a. m. | + 94 | 14.5 | − 36 | −118 | Drizzle and fog. |
| | 10 30 a. m. | + 98 | 16 | − 29 | −126 | Do. |
| | 4 p. m. | + 38 | 19 | − 16 | −177 | Overcast. |
| July 11 | 7 30 a. m. | +107 | 15 | − 33 | −128 | Clear. |
| | 11 a. m. | − 2 | 23 | − 0 | −116 | Do. |
| | 2 30 p. m. | − 66 | 23.5 | − 0 | −108 | Do. |
| | 3 15 p. m. | − 66 | 23.5 | − 3 | −100 | Do. |
| | 4 30 p. m. | − 60 | 27 | − 9 | − 98 | Do. |
| July 12 | 8 a. m. | +122 | 17 | − 12 | −122 | Do. |
| | 10 30 a. m. | + 7 | 24 | + 7 | −113 | Do. |
| July 13 | 7 30 a. m. | + 60 | 14 | − 32 | −138 | Do. |
| | 9 30 a. m. | + 30 | 20 | − 8 | −116 | Do. |
| | 12 m. | − 12 | 22.5 | + 5 | −114 | Do. |
| | 3 30 p. m. | − 50 | 26 | − 3 | −112 | Do. |
| July 14 | 7 30 a. m. | + 60 | 15 | − 36 | −132 | Do. |
| | 11 15 a. m. | + 17 | 19.5 | − 18 | −126 | Clouds. |
| | 2 15 p. m. | − 21 | 23 | − 14 | −117 | |
| July 15 | 7 30 a. m. | + 25 | 13 | − 51 | −138 | Fog. |
| | 9 30 a. m. | + 18 | 16 | − 35 | −130 | Clear. |
| | 1 30 p. m. | − 24 | 19 | − 36 | −137 | Do. |
| July 16 | 7 a. m. | + 12 | 14.5 | − 48 | −138 | Do. |
| | 11 a. m. | − 28 | 19 | − 36 | −130 | Do. |
| | 3 p. m. | − 48 | 22.5 | − 36 | −127 | Clear. |
| July 17 | 7 a. m. | + 15 | 15 | − 35 | −126 | Do. |
| | 3 15 p. m. | − 52 | 23 | − 36 | −124 | Do. |
| July 18 | 7 a. m. | + 12 | 15 | − 48 | −142 | Clouds. |
| | 11 30 a. m. | − 24 | 19.5 | − 24 | −129 | Do. |
| | 4 p. m. | − 30 | 19 | − 36 | −130 | Do. |
| July 19 | 7 40 a. m. | − 8 | 17 | − 42 | −140 | Do. |
| | 10 a. m. | − 24 | 18 | − 37 | −138 | Do. |
| | 5 p. m. | − 8 | 17 | − 47 | −141 | Do. |
| July 20 | 7 a. m. | − 2 | 14.5 | − 60 | −147 | Cloudy. |
| | 11 30 a. m. | − 15 | 18 | − 39 | −139 | Do. |
| | 3 30 p. m. | − 44 | 24.5 | − 28 | −135 | Clear. |
| July 21 | 7 a. m. | − 0 | 15 | − 54 | −146 | Overcast. |
| | 11 a. m. | − 18 | 18 | − 42 | −118 | Do. |
| | 4 p. m. | − 31 | 18 | − 42 | −144 | Clouds. |
| July 22 | 7 a. m. | − 1 | 14 | − 66 | −151 | Drizzle. |
| | 11 a. m. | ......... | 15 | − 67 | −151 | |
| | 4 30 p. m. | − 20 | 18 | − 53 | −146 | Overcast. |
| July 23 | 8 a. m. | − 0 | 14.5 | − 68 | −153 | Do. |
| | 11 45 a. m. | − 41 | 19 | − 42 | −137 | Clear. |
| | 4 p. m. | − 28 | 22 | − 45 | −137 | Do. |
| July 24 | 7 30 a. m. | − 6 | 13 | − 71 | −160 | Cloudy. |
| | 4 p. m. | − 31 | 21 | − 50 | −147 | Clouds. |
| | 8 p. m. | − 10 | 15 | − 66 | −153 | |
| July 25 | 7 30 a. m. | + 2 | 13 | − 74 | −158 | Overcast. |
| | 9 a. m. | − 0 | 15 | − 60 | −153 | Clear. |
| | 12 m. | − 25 | 19 | − 48 | −142 | Do. |
| | 3 p. m. | − 24 | 19 | − 55 | −150 | Clouds. |
| July 26 | 7 30 a. m. | + 9 | 13 | − 78 | −162 | Air released from instrument at end of long branch; reset at 0. |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Temperature. | Short branch. | Long branch. | Remarks. |
|---|---|---|---|---|---|---|
| 1925 | | | °C. | | | |
| July 6 | 10h m a. m. | ......... | 15 | − 69 | − 10 | |
| | 3 p. m. | − 17 | 18 | − 60 | −138 | Again reset at −132. Overcast. |
| July 27 | 7 30 a. m. | + 5 | 13 | − 75 | −134 | Overcast. |
| | 11 30 a. m. | − 5 | 15 | − 67 | −134 | Do. |
| | 2 30 p. m. | − 12 | 17 | − 63 | −133 | Do. |
| July 28 | 7 a. m. | + 3 | 13 | − 79 | −138 | Do. |
| | 11 a. m. | − 7 | 16 | − 66 | −134 | Do. |
| | 2 p. m. | − 14 | 19 | − 54 | −134 | Clear. |
| July 29 | 7 40 a. m. | + 2 | 13 | − 75 | −139 | Overcast. |
| July 30 | 8 a. m. | + 3 | 13 | − 75 | −138 | Dripping fog. |
| | 4 p. m. | − 14 | 17 | − 64 | −134 | Overcast. |
| July 31 | 7 30 a. m. | − 4 | 13 | − 76 | −141 | Do. |
| | 11 30 a. m. | − 12 | 17 | − 62 | −137 | Clearing. |
| Aug. 2 | 3 45 p. m. | − 14 | 18 | − 63 | −137 | Do. |
| Aug. 3 | 7 30 a. m. | − 3 | 12 | − 83 | −147 | Overcast. |
| | 11 30 a. m. | − 18 | 18 | − 60 | −133 | Clear. |
| | 3 40 p. m. | − 18 | 22 | − 54 | −137 | Do. |
| Aug. 4 | 8 a. m. | − 0 | 12 | − 80 | −147 | Overcast. |
| | 2 30 p. m. | − 13 | 18 | − 60 | −141 | Clear. Air released from short branch; reset at 60. |
| Aug. 5 | 9 a. m. | − 2 | 13 | − 48 | −150 | Overcast. |
| Aug. 6 | 2 30 p. m. | − 18 | 23 | − 15 | −132 | Clear. |
| Aug. 7 | 9 a. m. | − 9 | ......... | − 39 | −147 | Do. |
| | 4 p. m. | − 28 | 22 | − 19 | −139 | Do. |
| Aug. 8 | 8 a. m. | − 3 | 14.5 | − 42 | −147 | Fog. |

| Date. | Time. | Tangential. | Radial. | Temperature. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1925 | | | | °C. | | | |
| Aug. 8 | 9h30m a. m. | − 5 | ....... | 18 | −42 | −150 | Overcast. A radial bore was now made 7 cm. in depth above and parallel to tangential bore and 30 cm. from base of short stub of branch, and 30° from it. Readings are given in separate columns. |
| | 10 30 a. m. | − 8 | ....... | ....... | −38 | −148 | Overcast. |
| | 7 p. m. | −26 | − 3 | ....... | −33 | −135 | Clearing. Air released from instrument on radial bore; reset to 0. |
| Aug. 10 | 8 a. m. | − 7 | − 0 | 15 | −39 | −146 | Clear. |
| | 11 a. m. | −15 | −55 | ....... | −48 | −152 | Overcast. |
| | 4 p. m. | −27 | −64 | ....... | −26 | −148 | Clear. Air released from instrument on short stub; reset to 0. |
| Aug. 11 | 8 a. m. | − 4 | −45 | 15 | −12 | −146 | Clear. |
| | 11 30 a. m. | −24 | −48 | 20 | −12 | −137 | Do. |
| | 7 p. m. | −24 | −16 | ....... | −32 | −151 | Do. |
| Aug. 12 | 7 30 a. m. | − 0 | −48 | 15 | −30 | −151 | Do. |
| | 11 30 a. m. | −19 | −47 | 21 | −16 | −137 | Do. |
| | 4 15 p. m. | −30 | −54 | ....... | −24 | −149 | Do. |
| Aug. 13 | 7 30 a. m. | 0 | −51 | 13 | −51 | −160 | Overcast. |
| | 11 30 a. m. | − 7 | −48 | 18 | −33 | −158 | Do. |
| | 7 p. m. | −28 | −54 | 18 | −48 | −156 | Clear afternoon. |
| Aug. 14 | 5 45 a. m. | + 8 | −51 | 12 | −63 | −164 | Overcast. |
| | 8 45 a. m. | + 5 | −47 | 15 | −47 | −158 | Clearing. |
| Aug. 15 | 11 a. m. | − 7 | −45 | 17 | −48 | −159 | Overcast. |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Radial. | Temperature. | Short stub. | Long branch. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1925 | | | | *C.* | | | |
| Aug. 16 | 7h30m a. m. | 0 | −57 | 15 | −57 | −162 | Overcast. |
| | 4 p. m. | − 9 | −48 | 18 | −51 | −160 | Do. |
| Aug. 17 | 7 30 a. m. | + 6 | −51 | 15 | −66 | −165 | Clear at 9h30m a. m. |
| | 11 30 a. m. | −12 | −56 | 20 | −56 | −144 | |
| | 4 p. m. | −21 | −59 | 19 | −51 | −158 | Clear. |
| Aug. 18 | 7 30 a. m. | +12 | −45 | 13 | −56 | −162 | Do. |
| | 11 a. m. | −12 | −41 | 20 | −43 | −150 | Do. |
| | 4 p. m. | −21 | −51 | 20 | −56 | −162 | |
| Aug. 19 | 7 a. m. | +14 | −48 | 12 | −75 | −170 | Do. |
| | 11 45 a. m. | −15 | −40 | 20 | −44 | −152 | Do. |
| | 4 15 p. m. | −27 | −54 | 18 | −60 | −165 | Do. |
| Aug. 20 | 7 30 a. m. | + 2 | −51 | 14 | −75 | −174 | Overcast. |
| | 11 30 a. m. | −10 | −45 | 18 | −56 | −147 | Clear. |
| Aug. 21 | 3 30 p. m. | −32 | −54 | 22 | −50 | −162 | Do. |
| Aug. 22 | 8 a. m. | + 2 | −49 | 18 | −43 | −165 | Do. |
| | 11 30 a. m. | −18 | −48 | 22 | −55 | −153 | Do. |
| | 5 p. m. | −42 | −65 | 20 | −60 | −160 | Clear.[1] |

| Date. | Time. | Tangential. | Radial. | Temperature. | Short stub. | Long branch. | Root. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Terminal. | Stump. | |
| 1925 | | | | °*C.* | | | | | |
| Aug. 23 | 11h15m a. m. | − 13 | − 19 | ...... | 0 | − 10 | − 4 | +118 | Air was released from all manometers except that on detached root at 8 a. m. on 23d and reset to 0. |
| | 4 30 p. m. | − 24 | − 43 | ...... | − 6 | − 18 | − 28 | +138 | |
| Aug. 24 | 7 30 a. m. | − 10 | − 48 | 16 | − 1 | − 21 | + 14 | +156 | Pressure in stump of root was +118, which was not disturbed. |
| | 11 30 a. m. | − 24 | − 60 | ...... | + 14 | − 12 | − 21 | + 91 | |
| | 4 p. m. | − 23 | − 74 | ...... | − 27 | − 27 | − 38 | + 87 | Clear. |
| Aug. 25 | 7 30 a. m. | + 2 | − 62 | ...... | − 24 | − 33 | + 16 | +108 | Do. |
| | 11 30 a. m. | − 12 | − 58 | 14 | − 5 | − 21 | − 17 | + 96 | Do. |
| Aug. 26 | 8 a. m. | − 9 | − 72 | ...... | − 19 | − 35 | − 27 | + 84 | Do. |
| | 11 30 a. m. | − 13 | − 63 | ...... | − 40 | − 45 | − 12 | +84 | Overcast. |
| | 7 15 p. m. | − 11 | − 62 | ...... | − 53 | − 54 | ...... | ...... | |
| Aug. 27 | 6 a. m. | − 8 | − 68 | 12 | − 51 | − 55 | − 21 | + 71 | Do. |
| | 7 a. m. | − 7 | − 67 | 12 | − 36 | − 53 | − 21 | + 70 | Clear. |
| | 8 a. m. | − 7 | − 62 | 16 | − 32 | − 48 | − 9 | + 75 | Clouds. |
| | 9 a. m. | − 21 | − 60 | 18 | − 24 | − 47 | + 5 | + 78 | Do. |
| | 10 a. m. | − 21 | − 63 | 19 | − 24 | − 41 | + 5 | + 78 | |
| | 11 a. m. | − 23 | − 63 | ...... | − 26 | − 43 | + 6 | + 73 | Do. |
| | 12 m. | − 30 | − 66 | 20 | − 32 | − 47 | + 3 | + 71 | |
| | 2 p. m. | − 38 | − 71 | 18 | − 33 | − 48 | − 3 | + 66 | Overcast. |
| | 3 p. m. | − 41 | − 73 | 17 | − 36 | − 50 | − 6 | + 62 | Do. |
| | 4 p. m. | − 39 | − 74 | 15 | − 50 | − 51 | − 9 | + 57 | Do. |
| | 5 p. m. | − 38 | − 76 | 13 | − 50 | − 55 | − 15 | + 56 | Do. |
| | 8 p. m. | − 30 | − 78 | 10 | − 61 | − 60 | − 24 | + 44 | Do. |
| | 11 p. m. | − 20 | − 81 | 10 | − 66 | − 60 | − 32 | + 36 | Overcast. |
| Aug. 28 | 3 a. m. | − 15 | − 79 | 10 | − 65 | − 62 | − 29 | + 35 | Do. |
| | 4 a. m. | − 15 | − 80 | 10 | − 65 | − 62 | − 18 | + 36 | Do. |
| | 6 a. m. | − 17 | − 78 | 10 | − 59 | − 60 | − 15 | + 36 | Do. |

[1] Root lying 30 cm. deep was cut 1.6 meters from base of trunk when it showed a diameter of 24 to 26 mm. and a section 30 cm. long removed. Manometers with open ends were attached by wired sections of pressure hose to terminal of part attached to tree and to stump of detached part. Apparatus was completely fixed Aug. 22, 4.30 p. m. Suction of −12 mm. was shown by terminal of root within a half hour, and −40 mm. Hg. by stump of detached part.

TABLE 22.—*Continued.*

| Date. | Time. | Tan-gential. | Radial. | Tem-pera-ture. | Short stub. | Long branch. | Root. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ter-minal. | Stump. | |
| 1925 | | | | °C. | | | | | |
| Aug. 28 | 8h m a. m. | − 17 | − 74 | 10 | − 50 | − 57 | − 8 | + 38 | Overcast. |
| | 9 a. m. | − 21 | − 71 | 12 | − 37 | − 52 | + 3 | + 43 | Clear. |
| | 10 a. m. | − 19 | − 68 | 13 | − 41 | − 53 | + 9 | + 44 | Do. |
| | 11 a. m. | − 21 | − 69 | 15 | − 37 | − 51 | + 8 | + 43 | Do. |
| | 2 p. m. | − 30 | − 72 | 16 | − 43 | − 55 | + 2 | + 36 | Do. |
| | 4 p. m. | − 33 | − 75 | 18 | − 54 | − 60 | − 1 | + 31 | Clear at sunset. |
| | 7 p. m. | − 29 | − 80 | 15 | − 62 | − 62 | − 19 | + 15 | Overcast. |
| | 9 p. m. | − 18 | − 81 | 12 | − 66 | − 66 | − 25 | + 9 | Do. |
| Aug. 29 | 3 a. m. | − 15 | − 77 | 12 | − 64 | − 65 | − 15 | + 3 | Do. |
| | 4 a. m. | − 22 | − 77 | 12 | − 63 | − 66 | − 15 | + 3 | Do. |
| | 6 a. m. | − 17 | − 75 | 13 | − 65 | − 66 | − 13 | − 0 | Do. |
| Aug. 30 | 9 a. m. | − 19 | − 66 | 15 | − 67 | − 72 | − 10 | − 21 | Fog and heavy dew. |
| | 12 m. | − 63 | − 64 | 18 | − 48 | − 63 | + 3 | − 18 | Clear. |
| | 6 p. m. | − 31 | − 78 | 17 | − 62 | − 72 | − 18 | − 22 | Do. |
| Aug. 31 | 9 a. m. | − 19 | − 68 | 15 | − 63 | − 72 | + 7 | − 32 | Overcast. |
| | 4 p. m. | − 38 | − 78 | 20 | − 54 | − 71 | − 3 | − 36 | Clouds. |
| Sept. 1 | 7 a. m. | − 18 | − 75 | 13 | − 75 | − 83 | − 3 | − 48 | |
| | 12 m. | − 22 | − 68 | 21 | − 45 | − 66 | + 8 | − 43 | Clear. |
| | 7 p. m. | − 35 | − 92 | 15 | − 74 | − 84 | − 18 | − 60 | Do. |
| Sept. 2 | 7 a. m. | − 15 | − 72 | 12 | − 81 | − 72 | + 12 | − 63 | Clear. Air released from radial bore; column reset at −72. |
| | 11 a. m. | − 22 | − 75 | 20 | − 54 | − 72 | + 17 | − 54 | Clear. |
| Sept. 5 | 11 a. m. | − 26 | − 80 | ...... | − 55 | − 71 | − 0 | − 90 | Do. |
| | 6 30 p. m. | − 31 | − 87 | ...... | − 72 | − 98 | − 2 | −108 | Clouds. |
| Sept. 6 | 8 30 a. m. | − 14 | − 94 | ...... | − 75 | −102 | + 2 | −129 | Clearing. |
| | 6 p. m. | − 30 | − 78 | 20 | − 63 | − 98 | − 3 | −106 | Clear. |
| Sept. 7 | 7 30 a. m. | − 12 | − 74 | ...... | − 80 | −105 | − 0 | −110 | Clear. |
| | 11 15 a. m. | − 33 | − 72 | 21 | − 62 | − 92 | − 0 | −104 | |
| | 4 30 p. m. | − 32 | − 31 | 20 | − 73 | −103 | − 3 | −114 | |
| Sept. 8 | 7 30 a. m. | − 5 | − 75 | 14 | − 87 | −111 | + 3 | −122 | |
| | 11 30 a. m. | − 33 | − 72 | ...... | − 63 | − 94 | − 3 | −108 | Clear. Air released from short stub; reset at —63. |
| | 4 p. m. | − 25 | − 81 | 20 | − 80 | −108 | − 3 | −114 | Clear. |
| Sept. 9 | 8 a. m. | − 10 | − 78 | ...... | − 98 | −118 | − 6 | −127 | Do. |
| | 11 30 a. m. | − 24 | − 48 | 22 | − 75 | −104 | − 5 | −115 | Cloudy. |
| Sept. 10 | 7 30 a. m. | − 6 | − 30 | 15 | − 96 | −123 | − 3 | −132 | Clearing. |
| Sept. 13 | 8 a. m. | − 6 | − 32 | 10 | − 98 | −134 | − 3 | −138 | Clear. |
| | 6 p. m. | − 32 | − 50 | 17 | −102 | −137 | − 5 | −144 | Do. |
| Sept. 14 | 7 15 a. m. | − 2 | − 42 | 11 | −114 | −144 | − 1 | −152 | Do. |
| | 11 30 a. m. | − 36 | − 48 | 20 | − 90 | −124 | − 3 | −132 | Do. |
| | 4 p. m. | − 33 | − 54 | 20 | − 97 | −135 | − 5 | −141 | Do. |
| Sept. 15 | 7 15 a. m. | + 3 | − 56 | 12 | −110 | −141 | + 3 | −156 | Clear. |
| | 3 30 p. m. | − 33 | − 60 | 22 | − 88 | −134 | − 5 | −134 | Do. |
| Sept. 16 | 7 30 a. m. | + 9 | − 57 | 14 | −106 | −144 | + 1 | −152 | Do. |
| Sept. 18 | 7 a. m. | − 3 | − 74 | 11 | −135 | −151 | + 0 | −150 | Do. |
| Sept. 20 | 9 a. m. | + 3 | − 66 | 15 | −104 | −153 | + 5 | −145 | Do. |
| Sept. 21 | 7 30 a. m. | − 10 | − 75 | 13 | −114 | −162 | + 3 | −156 | Do. |
| | 11 30 a. m. | − 20 | − 61 | 25 | − 88 | −136 | ...... | ...... | Do. |
| | 4 p. m. | − 42 | − 72 | 20 | −108 | −161 | − 22 | −150 | Do. |
| Sept. 22 | 7 30 a. m. | − 7 | − 68 | 15 | −111 | −156 | + 3 | −156 | Do. |
| | 11 30 a. m. | − 19 | − 63 | 24 | − 96 | −152 | − 10 | −132 | Do. |
| | 5 30 p. m. | − 12 | − 70 | 18 | −115 | −169 | − 12 | −151 | Cloudy. |
| Sept. 23 | 8 a. m. | + 4 | − 72 | 12 | −132 | −178 | − 4 | −160 | Do. |
| | 12 m. | + 12 | − 60 | ...... | −108 | −154 | − 4 | −142 | Do. |
| | 4 p. m. | − 3 | − 59 | 19 | −116 | −171 | − 9 | −150 | Do. |

TABLE 22.—*Continued.*

| Date. | Time. | Tangential. | Radial. | Temperature. | Short stub. | Long branch. | Root. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Terminal. | Stump. | |
| 1925 | | | | °C. | | | | | |
| Sept. 24 | $7^h15^m$ a. m. | + 18 | − 66 | 12 | −134 | −182 | − 6 | −165 | Clearing. |
| | 11 30 a. m. | − 16 | − 54 | 17 | −116 | −176 | + 2 | −144 | Clouds. |
| | 4 p. m. | − 1 | − 56 | 19 | −117 | −177 | − 15 | −150 | Clear. |
| Sept. 25 | 8 a. m. | + 10 | − 48 | 13 | −120 | −180 | + 5 | −158 | Do. |
| | 5 p. m. | − 30 | − 54 | 18 | −118 | −181 | − 14 | −150 | Do. |
| Sept. 26 | 7 15 a. m. | − 4 | − 65 | 12 | −132 | −182 | − 1 | −162 | Do. |
| | 11 45 a. m. | − 12 | − 41 | 23 | −103 | −168 | − 3 | −128 | Do. |
| | 4 p. m. | − 32 | − 42 | 21 | −114 | −181 | − 13 | −148 | Do. |
| Sept. 28 | 7 30 a. m. | + 0 | − 56 | 15 | −128 | −192 | − 3 | −168 | Air released from radial bore; reset to −56. |
| Sept. 29 | 9 45 a. m. | − 10 | − 60 | 13 | −130 | −195 | + 10 | −162 | Clear. |
| Sept. 30 | 4 p. m. | − 22 | − 57 | 23 | −116 | −192 | − 15 | −144 | Clear. Air released from 4 instruments on trunk and branches; reset at 0. |
| Oct. 4 | 9 a. m. | ...... | − 30 | 21 | − 48 | − 58 | + 27 | −156 | Clear. Stopcock left open on tangential bore. |
| | 4 p. m. | ...... | − 22 | ...... | − 57 | − 64 | − 18 | −165 | Clear. |
| Oct. 5 | 7 30 a. m. | ...... | − 37 | 10 | − 70 | − 74 | − 4 | −183 | Do. |
| | 2 30 p. m. | ...... | − 24 | ...... | − 45 | − 70 | + 3 | −150 | Clouds. |
| Oct. 6 | 7 30 a. m. | ...... | − 38 | 11 | − 75 | − 80 | − 6 | −186 | Clear. |
| | 5 p. m. | ...... | − 30 | 19 | − 70 | − 79 | − 18 | −168 | Do. |
| Oct. 7 | 7 45 a. m. | + 14 | − 42 | 12 | − 78 | − 86 | − 2 | −188 | Clear. Stopcock closed on tangential bore. |
| | 12 m. | − 6 | − 26 | 25 | − 51 | − 78 | + 17 | −158 | Clear. |
| | 3 15 p. m. | − 27 | − 30 | 23 | − 67 | − 84 | − 14 | −168 | Do. |
| | 6 30 p. m. | − 27 | − 38 | 17 | − 84 | − 90 | − 42 | −186 | Do. |
| Oct. 8 | 7 30 a. m. | − 5 | − 44 | 10 | − 94 | − 96 | − 8 | −192 | Do. |
| | 4 p. m. | − 26 | − 38 | 22 | − 77 | − 91 | − 15 | −176 | Do. |
| Oct. 9 | 7 30 a. m. | − 3 | − 49 | 12 | − 93 | −102 | − 3 | −192 | Clouds. |
| | 3 30 p. m. | − 0 | − 42 | 17 | − 84 | − 99 | − 3 | −172 | Do. |
| Oct. 10 | 8 a. m. | − 5 | − 39 | 15 | − 96 | −106 | − 5 | −182 | Overcast. |
| | 12 m. | − 0 | − 41 | 17 | − 89 | −104 | + 4 | −172 | Do. |
| | 4 p. m. | − 2 | − 42 | 17 | − 92 | −106 | − 9 | −178 | Do. |
| Oct. 11 | 8 a. m. | + 4 | − 44 | 15 | −104 | −111 | − 7 | −182 | Do. |
| Oct. 12 | 8 a. m. | + 6 | − 48 | 9 | −112 | −121 | − 18 | −196 | Cloudy, raining since noon of 11th. |
| | 4 p. m. | − 13 | − 38 | 18 | − 96 | −116 | + 2 | −178 | Cloudy. Clear in afternoon. |
| Oct. 13 | 8 a. m. | + 12 | − 51 | 9 | −111 | −125 | − 20 | −196 | Clear. |
| | 2 p. m. | − 12 | − 34 | 22 | − 91 | −120 | + 5 | −160 | Do. |
| Oct. 14 | 8 a. m. | − 8 | − 50 | 10 | −114 | −128 | − 18 | −191 | Do. |
| Oct. 16 | 9 a. m. | + 7 | − 42 | 13 | −119 | −134 | − 20 | −182 | Cloudy. |
| | 4 p. m. | − 3 | − 38 | 16 | −115 | −134 | − 19 | −172 | Do. |
| Oct. 17 | 9 a. m. | + 4 | − 39 | 13 | −122 | −140 | − 30 | −195 | Do. |
| Oct. 18 | 8 a. m. | + 4 | − 48 | 11 | −123 | −146 | − 19 | −188 | Clear. |
| Oct. 19 | 9 a. m. | − 2 | − 45 | 13 | −122 | −148 | − 26 | −194 | Do. |
| | 4 p. m. | − 30 | − 22 | 23 | −106 | −142 | − 6 | −172 | Do. |
| Oct. 20 | 7 30 a. m. | − 13 | − 45 | 14 | −120 | −150 | − 27 | −190 | Do. |
| | 2 p. m. | − 28 | − 22 | 25 | −105 | −144 | − 2 | −162 | Do. |
| Oct. 21 | 8 a. m. | − 12 | − 51 | 15 | −122 | −156 | − 27 | −187 | Do. |
| Oct. 22 | 4 p. m. | − 3 | − 46 | 19 | −122 | −158 | − 24 | −175 | Do. |
| Oct. 23 | 7 a. m. | + 2 | − 60 | 13 | −136 | −164 | − 45 | −186 | Do. |
| | 11 a. m. | − 3 | − 42 | 21 | −110 | −153 | − 9 | −162 | Do. |
| Oct. 24 | 7 a. m. | + 5 | − 67 | 14 | −144 | −170 | − 54 | −198 | Do. |
| | 12 m. | − 4 | − 37 | 24 | − 81 | −158 | − 4 | −158 | Do. |
| | 7 p. m. | − 18 | − 48 | 15 | −135 | −167 | − 42 | −180 | Do. |

TABLE 22.—*Continued.*

| Date. | Time. | Tan-gential. | Radial. | Tem-pera-ture. | Short stub. | Long branch. | Root. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ter-minal. | Stump. | |
| 1925 | | | | °C. | | | | | |
| Oct. 25 | 8h m a. m. | − 5 | − 60 | 14 | −134 | −170 | − 30 | −182 | Clear. |
| Oct. 26 | 7 30 a. m. | − 16 | − 60 | 15 | −136 | −177 | − 39 | −187 | Do. |
| Oct. 27 | 8 a. m. | + 5 | − 66 | 12 | −146 | −186 | − 42 | −186 | Do. |
| | 4 p. m. | − 3 | − 51 | 17 | −124 | −139 | − 30 | −180 | Do. |
| Oct. 28 | 7 30 a. m. | + 3 | − 66 | 11 | −150 | −192 | − 41 | −190 | Overcast. |
| | 4 p. m. | − 1 | − 50 | 15 | −138 | −186 | − 20 | −170 | Do. |
| Oct. 29 | 2 p. m. | − 3 | − 36 | 20 | −129 | −180 | − 19 | −162 | Clear. |
| Oct. 30 | 7 30 a. m. | + 4 | − 57 | 11 | −150 | −188 | − 44 | −198 | Overcast. |
| Oct. 31 | 8 a. m. | + 2 | − 45 | 14 | −144 | −199 | − 36 | −170 | Do. |
| Nov. 1 | 10 30 a. m. | + 5 | − 42 | 15 | −140 | −204 | − 32 | −140 | Do. |
| Nov. 2 | 8 a. m. | + 4 | − 44 | 12 | −149 | −204 | − 37 | −171 | Showers. |
| Nov. 3 | 9 a. m. | + 4 | − 53 | 9 | −152 | −205 | − 37 | −168 | Clearing. |
| Nov. 4 | 8 a. m. | − 0 | − 43 | 9 | −153 | −207 | − 45 | −174 | Clear. |
| | 4 p. m. | − 3 | − 38 | ...... | −142 | −204 | − 36 | −156 | Do. |
| Nov. 5 | 8 a. m. | − 0 | − 63 | 60 | −160 | −228 | − 54 | −178 | Do. |
| | 4 p. m. | − 7 | − 41 | 14 | −148 | −204 | − 42 | −168 | Do. |
| Nov. 6 | 8 a. m. | − 6 | − 66 | 4 | −165 | −232 | − 48 | −178 | Do. |
| | 3 p. m. | − 4 | − 40 | 15 | −139 | −204 | − 20 | −144 | Do. |
| Nov. 7 | 8 a. m. | + 2 | − 60 | 5 | −158 | −222 | − 41 | −168 | Do. |
| Nov. 8 | 10 a. m. | + 12 | − 37 | 14 | −135 | −218 | − 18 | −138 | Do. |
| Nov. 9 | 8 a. m. | − 2 | − 50 | 5 | −150 | −231 | − 56 | −163 | Do. |
| | 3 p. m. | − 4 | − 24 | 15 | −132 | −222 | − 8 | −138 | Cloudy. |
| Nov. 10 | 4 p. m. | − 3 | − 9 | 16 | −134 | −218 | − 15 | −126 | Do. |
| Nov. 11 | 7 30 a. m. | + 4 | − 19 | 14 | −139 | −234 | − 21 | −126 | Raining. |
| | 4 p. m. | − 0 | − 10 | 15 | −138 | −234 | − 18 | −126 | Do. |
| Nov. 12 | 8 a. m. | + 4 | − 20 | 15 | −151 | −240 | − 31 | −138 | Cloudy. |
| | 4 p. m. | − 5 | − 3 | 16 | −136 | −260 | − 18 | −126 | Raining. |
| Nov. 13 | 7 30 a. m. | − 3 | − 24 | 6 | −160 | −268 | − 50 | −156 | Clear. |
| Nov. 14 | 7 30 a. m. | − 5 | − 32 | 4 | −162 | −256 | − 54 | −156 | Do. |
| | 4 p. m. | − 4 | − 8 | 14 | −140 | −248 | − 30 | −138 | Do. |
| Nov. 15 | 8 a. m. | − 3 | − 27 | 7 | −136 | −256 | − 42 | −144 | Do. |
| | 1 30 p. m. | − 2 | − 0 | 18 | −126 | −246 | − 7 | −144 | Do. |
| | 6 p. m. | − 9 | − 10 | 12 | −148 | −257 | − 7 | −143 | Cloudy. |
| Nov. 16 | 8 a. m. | + 3 | − 8 | 12 | −142 | −256 | − 19 | −132 | Drizzle. |
| Nov. 17 | 7 30 a. m. | − 3 | − 18 | 7 | −156 | −260 | − 48 | −144 | Clear. |
| Nov. 18 | 7 30 a. m. | − 4 | − 9 | 7 | −155 | −265 | − 48 | −144 | Do. |
| | 11 30 a. m. | + 3 | + 14 | 19 | −129 | −252 | − 4 | −114 | Do. |
| | 2 p. m. | − 8 | + 15 | 22 | −121 | −248 | − 15 | −120 | Do. |
| | 7 p. m. | − 14 | − 2 | 10 | −150 | −264 | − 48 | −162 | Do. |
| Nov. 19 | 7 30 a. m. | − 10 | − 12 | 8 | −154 | −263 | − 48 | −138 | Do. |
| Nov. 20 | 8 a. m. | − 9 | − 7 | 8 | −150 | −266 | − 39 | −138 | Clear. Air released from short stub of branch. |
| | 11 30 a. m. | + 9 | + 26 | 22 | + 21 | −258 | + 3 | ...... | Clear. Stump of root taken up. |
| | 2 p. m. | − 5 | + 30 | 22 | + 4 | −250 | − 8 | ...... | Clear. |
| | 4 30 p. m. | − 14 | + 18 | 16 | − 12 | −258 | − 30 | ...... | Do. |
| Nov. 21 | 8 a. m. | − 12 | − 2 | 10 | − 29 | −260 | − 38 | ...... | Overcast. |
| | 12 m. | + 5 | + 24 | 18 | − 16 | −256 | + 3 | ...... | Slightly overcast. |
| | 4 p. m. | − 3 | + 24 | 18 | − 15 | −258 | − 8 | ...... | Overcast. |
| Nov. 22 | 8 a. m. | − 7 | − 2 | 9 | − 42 | −266 | − 37 | ...... | Clear. |
| Nov. 23 | 7 30 a. m. | − 11 | + 4 | 14 | − 40 | −268 | − 21 | ...... | Overcast. |
| Nov. 24 | 7 30 a. m. | − 2 | + 15 | 13 | − 50 | −265 | − 23 | ...... | Do. |
| | 2 p. m. | + 4 | + 30 | ...... | − 42 | −258 | − 8 | ...... | Clear. |
| Nov. 25 | 7 a. m. | − 4 | − 3 | 5 | − 75 | −267 | − 60 | ...... | Do. |
| | 2 p. m. | + 5 | + 25 | 13 | − 51 | −252 | − 13 | ...... | Hazy. Long branch reset at 0. |
| Nov. 26 | m. | + 8 | + 12 | 14 | − 59 | − 22 | − 9 | ...... | Hazy. |
| Nov. 27 | 8 a. m. | − 3 | − 3 | 5 | − 83 | − 38 | − 49 | ...... | Clear. |
| Nov. 28 | 8 a. m. | − 2 | + 6 | 8 | − 83 | − 47 | − 42 | ...... | Do. |

## COMPOSITION OF INTERNAL GASES OF JUGLANS.

In order to obtain a sample of the gases in the vessels of the older wood a radial bore was made into the trunk of the tree to which 6 manometers, a dendrograph and a thermometer were affixed. The cavity was 12 cm. in depth, 1 cm. in diameter and extended toward the center on the opposite side, and 25 cm. below the tangential bore. The gas receiver and column of mercury for producing suction were attached as in figure 10. The preparation was completed at 3 p. m. on October 19, 1925, and the column was set to give a suction of about −500 mm. Hg. At 4 p. m. 100 ml. of gas had been drawn out. At 4 p. m. on the 20th about 200 ml. gas had been drawn out, and an analysis was made with the following results: $CO_2$: 10.62 p. ct.; 10.63 p. ct. O: 9.96 p. ct.; 9.94 p. ct. N: 79.42 p. ct.

A section of the exhausting tube of rubber had been left uncoated and, as a consequence, some $CO_2$ was lost by diffusion; this error was rectified in a second extraction from the same bore which showed the following composition: $CO_2$: 12.13 p. ct.; 12.20 p. ct. $O_2$: 8.41 p. ct.; 8.41 p. ct. N: 79.43 p. ct.; 79.39 p. ct.

It is evident that gases may diffuse but slowly and against great resistance to allow the accumulation of proportions of $CO_2$ six-hundred times as great as in the air.

The activity of the living cells was not as great at this time as earlier in the season. Growth had ceased and the leaves were beginning to turn yellow and fall off.

## CONDITIONS AFFECTING TENSION, SUCTION AND PRESSURE IN JUGLANS.

The experiments by which the measurements given in the preceding pages were derived included arrangements of manometers by which pressures in the outer and inner wood, in a short stub of a branch, at the end of a long branch with many leafy branchlets, at the end of a heavy root with many laterals at a distance of 1.6 meters from the base of the trunk, and in the separated part of this root.

Such measurements are usually designated as showing "sap-pressure," and "negative-pressure," but they may be more accurately termed "suction" and exudation pressure of gases and liquids in the trunk. It has already been made plain in preceding discussions that suction may be due to capillarity in vessels in the wood cells, to the absorption of liquids by living cells and to connection with reservoirs of gases under pressures less than atmospheric in the older wood of the central part of the trunk.

Experimentors have hitherto agreed in concluding that no correlation could be established between manometric measurements in different bores or on stumps no matter how near together or widely

separated they might be. Such a condition may be safely attributed to the fact that nearly all observations have been made in such manner that it is impossible to determine what connections were made with the various parts of the hydrostatic system of the tree as illustrated in figure 1.

Attempts to define "periodicities" in pressures have also failed. The tensions and pressures in the trunk are affected primarily by the balance between water-loss and water-intake. A wide variety of factors influence the included processes. In addition, temperature

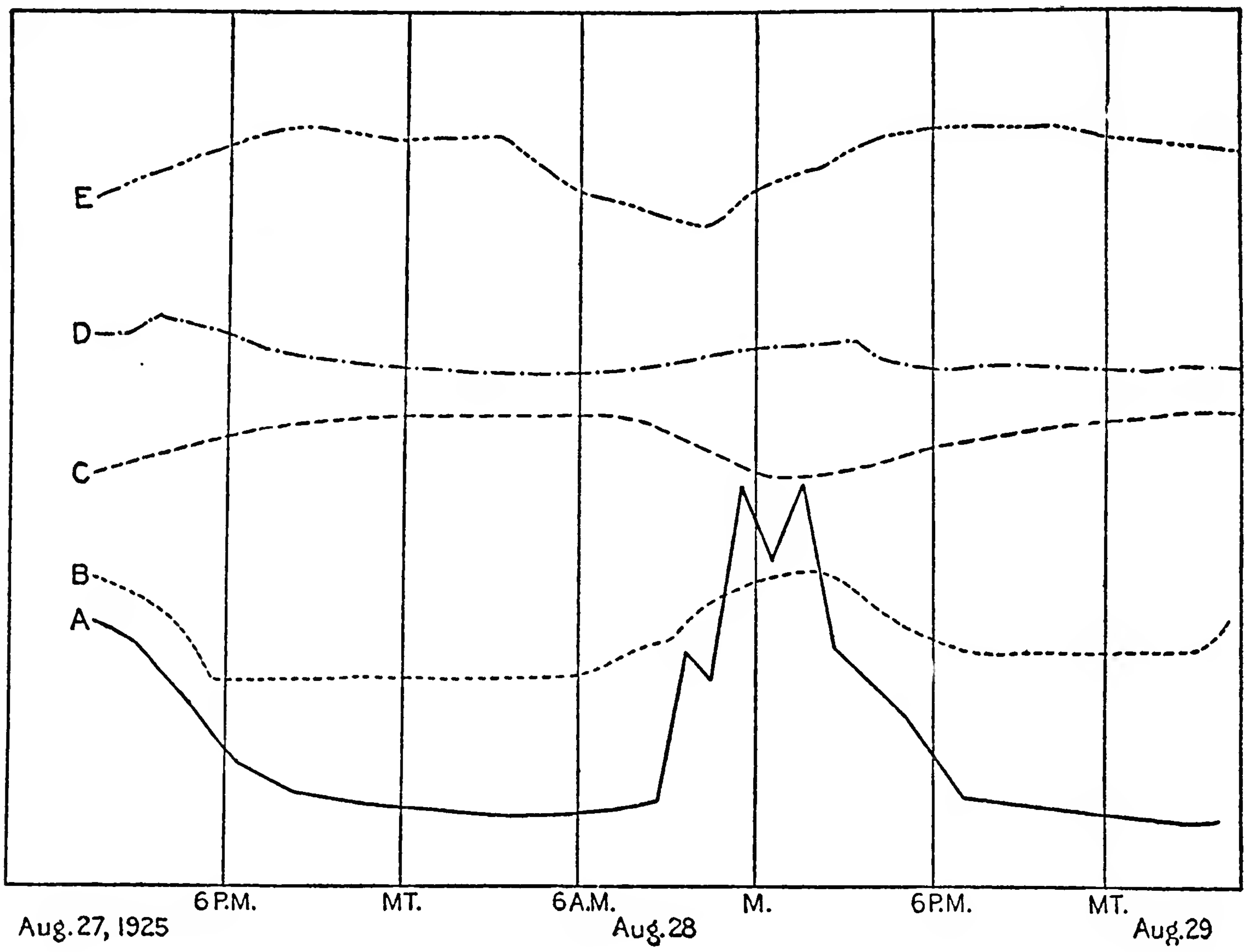


FIG. 20.—Graphs of suction, etc., of *Juglans*. A, course of water-loss from Livingston evaporimeter; B, temperature of outer layer of wood; C, dendrographic record of variation in diameter of the trunk; D, variations in suction in tangential bore, an increase in the period of high being recorded; E, variations in suction of radial bore, a decrease at time of highest temperature and greatest expansion of internal gases.

doubtless constitutes an important factor in modifying pressure and solubility of the gases. Simple or direct concurrence of manometric readings from bores or stumps are, therefore, not to be expected.

It is only when the nature of the connections made for each instrument are taken into account that some order appears in the chaos. It can not be claimed that an adequate explanation can be made of all the phenomena implied in the preceding measurements. This could only be done by the maintenance of a battery of instruments upon such a large number of trees that individuals could be taken down for dissection at frequent intervals. Minute records of stomatal

program and numerous gas analyses, with meteorological and soil studies, would also be necessary.

The work described, however, establishes the principal features of the hydrostatic system and delineates the features of its action. It is thus made possible upon the basis of the conceptions furnished to make detailed studies of any feature of the sap or the accessory gaseous system that may seem desirable.

In the more primitive system of the conifers, and in a tree like the Monterey pine, it is possible to drive tangential bores in wood in which comparatively little air is included. It may be safely taken for granted that any bore a few centimeters in depth with a diameter of 8 or 10 mm. made in the trunk of a walnut will cut many vessels

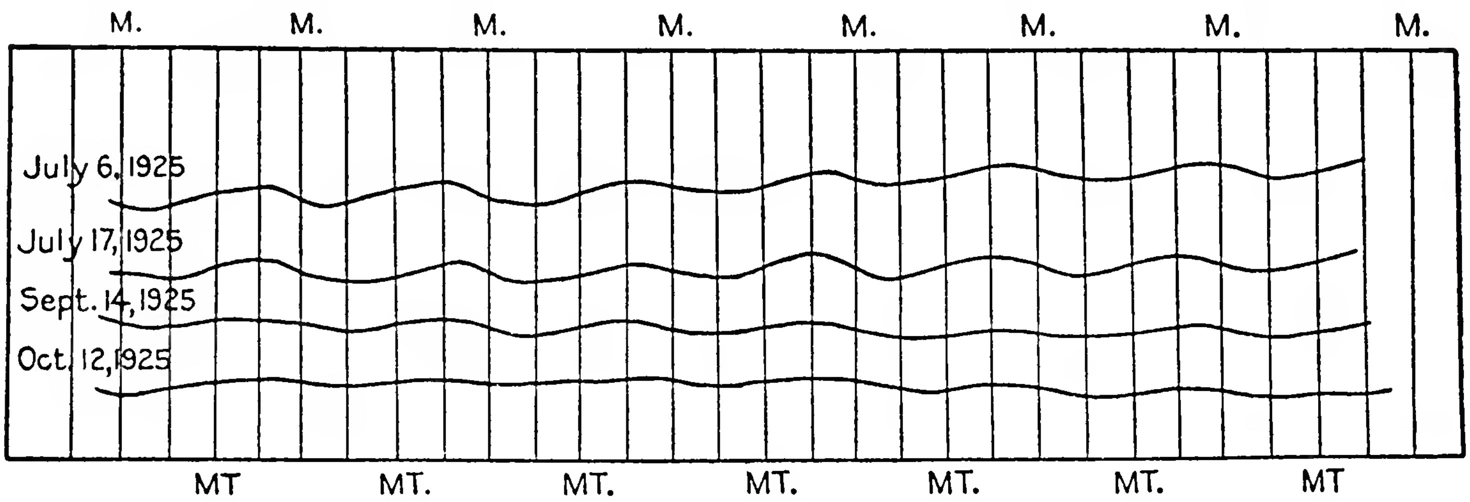


FIG. 21.—Dendrograph records of *Juglans major*. The week beginning July 6 was characterized by a wide range of daily variation in diameter with some permanent increase due to growth. High positive pressures in the tangential bore, low suction in the short stub of a branch and high suction pressures in the long branch were observed. The week beginning August 17 (July 17 by mistake in lettering) was characterized by alternations from suction to exudation in the tangential bore, high temperatures, abrupt changes in diameter, and suction in radial bore and in branches. Growth had ceased. Some positive pressures were recorded in the tangential bore in the week beginning September 14. Suction was high in other manometers on trunk and branches. Daily variation in diameter was near the minimum. High temperatures were observed in the week beginning October 12. Daily variation in diameter was near the minimum. Some exudation pressure in the tangential bore and at cut end of a root. Suction in radial bore and in branches.

containing gases. The results of the analyses show that carbon dioxide sustains a high partial pressure in these gases. When a bore connects with the gas-filled layers the water introduced dissolves these gases unequally, but to a total which must be of some consequence. The application of water to the exposed ends of the wood in a bore or at the cut end of a branch would connect directly with the water-column in the sap conduits, so that variations in tension in this layer would be registered directly and in a manner capable of simple interpretation after the initial adjustment is made. The manometer should within a day or two register the state of tension, or at least the course of changes in tension. Accuracy will depend on how exclusively connection is made with the sap-filled elements, tracheids, and tracheæ and to what extent liquid and gas replace each other in the elongated conducting elements. It might be expected,

under conditions in which the draft on the water-column was greatest, that the liquid would be exhausted in some of the larger vessels, at a time when a shrinkage of the trunk is taking place.

Diminution of the rate of water-loss would naturally be followed by replacement of gases by liquid in these vessels, if a supply is available. Now when water is applied to such tracts capillary action would result in filling all connecting vessels, as has been demonstrated in the oak. Tracheids would also be injected. This process draws water from the connecting tube of the manometer which causes a registration of "negative pressure" or suction, and which is difficult to separate from the effects of less than atmospheric pressure in the gases.

It being important to determine the extent to which stomatal action might affect the rate of water-loss and the tension in the sap-column, an examination of the action of these organs was made by Professor F. E. Lloyd, who has kindly furnished the following notes concerning their behavior in August when the leaves were fully mature and slightly yellowish and the soil-moisture had fallen to its minimum. These observations were made August 28, 1925, coincident with the intensive observations made with the manometers.

Material for the study of the behavior of the stomata with respect to their daily march of opening and closing was obtained by stripping and by slicing of thin pieces of epidermis and plunging the samples into absolute alcohol (the Lloyd method). It should be noted that the epidermis of this tree is quite difficult to strip, only narrow fringes of epidermis being obtained. The areas for unobstructed view of the stomata were, therefore, very small and seldom contained more than 10 or 15 stomata in any one area of free epidermis. The examination of such material affords the following data:

TABLE 23.

| Date. | Time. | Average width of open stomata pores. | Maximum opening and width. | Effective width. |
|---|---|---|---|---|
| 1925 | | $\mu$ | $\mu$ | $\mu$ |
| Aug. 27 | $10^h15^m$ a. m. | 2 | 4 | 1 |
| | | 1.5 | 2 | 0.75 |
| 27 | 2 p. m. | 1.5 | 2 | 0.3 |
| 27 | 7 p. m. | 1 | 1 | nearly 0 |
| 28 | 4 a. m. | 1.5 | 2 | 0.75 |
| 28 | 6 a. m. | 1.5 | 2 | 0.2 |
| 28 | 7 30 a. m. | 1.5 | 2 | 0.2 |
| 28 | 9 a. m. | 1.5 | 2 | 1 |
| 28 | 11 30 a. m. | 0 | 1.5 | 0 |
| 28 | 4 p. m. | 0 | 1 | 0 |

It will be noted that the above data indicate a rather meager mobility, and the natural question arose if these represented the limits of possibility in this regard. It was, therefore, necessary to determine, if possible, the extreme limits of mobility. In order to do this, pieces of living epidermis were floated upon distilled water. Control material from identical leaves were placed in absolute alcohol at once, this showing only a very few stomata open, the maximum width of pore $2\mu$. The material floated on distilled

water was fixed in alcohol at the close of 2 days, and showed upon examination that only about 15 per cent of the stomata were now closed, while the open stomata showed a range of pore width of 1 to 5$\mu$, the average width for the 80 per cent open stomata being about 3$\mu$. The difference between the stomata on the tree and those subjected to distilled water was striking and left no doubt that the limiting factor for stomata behavior on the tree lay not in their immobility, but rather in the external factors, which likely enough was the dryness of the soil. On this supposition the stomata of a succulent *Pelargonium* and *Vinca*, growing in dry sandy soil, and of *Helianthus annuus*, growing in well-watered soil, were examined, although there was no doubt that the *Vinca* and *Pelargonium* stomata had a high degree of mobility, as shown by distilled water. It was found that they were for the most part only narrowly open with a maximum of about 2$\mu$ for both young and old leaves, while the stomata of the sunflower showed a very ample movement amounting to a general aperture of from 5 to 7$\mu$ width. We may, therefore, in general conclude that the stomata of *Juglan* show, during a prevalence of soil and other conditions obtaining at the time of the examination, a minor amplitude of movement. It may, however, be noted in this connection that on sunshiny days during the middle of the day, the leaves show a net water-loss as indicated by their lack of crispness, quite notable when epidermis is being stripped.

It would appear, therefore, that the activity of the stomatal cells, in regulating the slits through which water vapor passes as it comes free from the menisci in the transpiring cells, is by no means so definite as the reversible variations in the thickness of the sap-carrying layers which is correlated with tension in the water-column in these layers.

The dendrographic record was begun in June, about 30 or 40 days after enlargement of the trunk had set in. Additions to the diameter continued until late in September, thus extending over a period which may be estimated at 130 to 140 days. The minimum for this tree is 95 days and the maximum 165 days, and the present observations were therefore made in a season near the mean for the locality.

Contraction of the stem began at daybreak on clear days early in the season and continued for about 6 to 8 hours (see fig. 21). Shortly after mid-day, the minimum was reached, after which enlargement began at a rate less than that of contraction, which decreased until daybreak when the reversal occurred. As will be shown in the review of the detailed records from the manometers, the morning period or dawn was marked by the prevalence of the greatest positive or exudation pressures, indicative of the least tensions in the sap-column, and by the highest suction in the gas-filled layers. Coincidental with contraction of the wood, and supposedly causally related to it, was increased tension of the sap-column by which positive pressure disappeared and suction began. At the same time suction became less in bores penetrating the inner wood containing much gas in which carbon dioxide was present in proportions as high as 12 per cent. These reactions characterize a growing trunk at the season when soil-moisture is adequate, relative humidity is high at night, while a

clear sky and sunshine with a rise of 8° to 12° C. in the temperature of the outer tissues facilitate transpiration. These simple conditions of the environic complex were presented on a few days only. Low heavy fogs caused dripping foliage in the early part of a large proportion of the days, while the sky was overcast by high fogs on many.

Contraction of the stem becomes very abrupt in late August, after which period the amplitude of shrinkage lessens.

Any explanation to be adequate must, of course, account for variations and conditions of tension under all circumstances. The basis of such explanations, however, may be most easily found by a consideration of selected "cases" or "runs" of the variations under simple combinations in which the greatest number of agencies affect tension or pressure concurrently, or harmoniously.

An inspection of the extensive records given on the preceding pages will confirm the statement that in any tapping of the tissues of the trunk of *Juglans* with a fitting of a manometer which applies water to the cut surfaces is followed directly by suction, which may be due to absorption by living cells, capillarity of vessels and wood, or the pull of a sap-column under tension. All of these conditions operate in varying proportions in almost any test.

### Suction and Pressure in a Tangential Bore.

Figure 19C.

At the beginning, May 17, 1925, instruments were applied to a tangential bore and to the end of a long branch of *Juglans*. Suction showed for 7 days in the tangential bore, the amount varying between 0 and −20 mm. Hg., with some air forced or drawn into the bore, presumably from vessels tapped. During the same period, the high initial suction in the branch varied from 5 to 80 mm. Hg., with much air coming from the vessels and medulla.

Eight days after the manometer had been fitted, a still of the pressures or tensions was noticeable which index the nature of the dominant agencies in each case unmistakably. Exudation pressures began to show in the tangential bore, which reached a maximum of +176 mm. Hg. early in July, at the height of the growing season, but which lessened and alternated with suction amounting to −110 mm. Hg. early in June. These extremes came within the period in which reversible variations were greatest. The reduction of pressure and the appearance of suction such as was shown May 26 and 31, June 4, 5, 24, 26, July 4, 5, 11, 13, 15, 16, 17, etc., was under conditions in which transpiration would be increasing. The reverse variation by which suction was lessened and positive pressures appeared was under conditions which would check water-loss, as illustrated by the records of May 26 and 27, 30 and 31, June 13 and 14, 15 and 17, 25 and 27, July 11–16, 24–25, etc.

The meteorological notations pertain to the hour at which the manometric reading was made, and the pressure or suction may have been determined almost wholly by conditions of the previous night or day. Thus change from pressure of +48 to suction −25 in the forenoon of May 27–29 is seen to be due to a steep rise and high maximum temperature. Suction on May 30–31 was a consequence of high temperature with light showers, which as soon as the rain ceased rose to −100 mm. Hg. This condition continued for several days, when it may be seen that fog or clouds lessened suction.

It is further notable that but little air came from this tangential bore and that the range of variation decreased toward the end of the season. The entire record seems clearly explainable on the basis of a water-column under tension, at times presumably from the transpiratory pull from the leaves and at other times under compression from the action of living cells. The seat of such pressure, ordinarily termed "root-pressure," is not easily to be fixed upon. It may not be attributed to temperature effects on included gases, as it is greatest concurrently with the greatest diameter at the time of lowest temperature. It may only be safely assigned to the action of living cells of the rays or xylem, or to the endodermal mechanism. The essential activity of these cells would continue at a varying rate as of osmosis and hydration affected by temperatures, but the actual pressure or tension registered would simply indicate the balance between such action and the pull from the leaves.

## Suction and Pressure in a Radial Bore.

The radial bore was not made until much later than the tangential one in the newer wood, but the essential differences between the complex of agencies operative here and in the tangential cavity are apparent. Chief among these is the fact that no positive or exudation pressure was shown until November. The tube fitted to the bore did not extend beyond all elements carrying the sap-column, and the capillary injection from the bore doubtless made some liquid connection with the ascending current. The increased transpiration would, therefore, be expected to cause some increase in the suction in the mid-day period, and this is well illustrated in the first few days of the record. This would be especially true on clear days. The gradual increase in suction, which was seen here as well as in all bores connecting with old wood, obscures the daily variation to some extent. Such an increase might not reach its maximum for a month after the column in the manometer was set to 0. Some deviations from the course of daily action by which the suction was least at mid-day might also be attributed to gases coming from the wood or from the atmosphere by reason of minute leaks in the fittings. Clearly defined action is illustrated by the records of August 11, 12, 13, 14, 18, 19, 20,

22, 25, 26, September 8, 9, 21, 24, October 4, 5, 6, 7, 8, 9, 12, 24, etc., in which transpiration and contraction of the stem have a mid-day maximum coincident with the greatest suction pressure or tension in the moving water-column.

The diminution of suction in the central gas-filled wood at the time of greatest water-loss has been one of the unexpected features of the extensive results described in this paper; especially since suction likewise reaches its maximum at the beginning of the day when transpiration is least. Direct connection of this kind is to be seen in the detailed records of August 27 and 28, although here, as elsewhere, irregularities appear. Late in the season when soil-moisture was low and growth had ceased the mid-day decrease of suction was an invariable feature of a clear day, and was even seen on cloudy days in which of course transpiration was something greater than at night.

The only agency, the variations of which run parallel in such manner as to suggest causal relations, is that of temperature. The records were obtained from a mercurial thermometer thrust tangentially into the new wood of the trunk, early in July. The formation of some new wood gave the bulb a relatively deeper position before the end of the season. The actual temperatures of the gas-filled wood would, of course, be neither so high nor so low as those of the outer wood from which the records were made, and the variations would lag behind those shown by the thermometer. The volume of the gas would vary according to the formula $V_{+}=V_0$ (1+atm.) at constant pressures, or approximately 1/273 for 1° variation, this coefficient being slightly greater for $CO_2$ than for oxygen and nitrogen. The variations in volume run nearly parallel with those of pressure in the range of these observations. Volume of the gases would also be modified to some extent by their solubility in the sap of the outer wood, which would run inversely to the temperature and thus accentuate the changes in volume of the gas.

If the record be examined with regard to this matter it will be seen that some correspondence prevails between the range of variation in temperature and of suction, but the correlation is by no means high or complete. Thus on August 13 the temperatures morning, noon and evening are 13°, 18°, and 18° C., the suction being 51, 48 and 54 mm. Hg.; likewise, on August 17 temperatures were 15°, 20° and 19° C., and suction 51, 56, and 59 mm. Hg. Similar records were made for August 18 and 19. The detailed observations of August 27 likewise fail to show direct relations between changes in gas volume and suction. The temperature of the trunk remained unchanged at 10° C. from sunset of August 27 to 8 a. m. on the 28th, and during this 12-hour period suction varied as follows: −78, 81, 79, 80, 78 and 74 mm. Hg. The daily rise in temperature gave readings of 12°, 13°, 15°, 16° and 18° C., a steady rise until 4 p. m., the suction varying

at the same time as follows: 71, 68, 69, 72, 75 mm. Hg. However, at 9 p. m. suction has decreased to 81 mm. with a temperature of 12° C. Later in the season suction appeared to follow variations determined by temperature, being greatest in the morning, decreasing in the warmer mid-day period and increasing again with the decreasing volume of cooling gases in the evening. This is well illustrated by the records of September 8, 14, 21, 22, 23, 24, October 7, 10, 24, and November 15.

Here as in all other preparations it can not be assumed that the radial bore taps only the gas-filled wood. The liquid from the bore injects the tracts which are cut across, and it is highly probable that connection is made with the ascending column under tension. The records cited make it obvious that the changes in volume of the gases included in the old wood of the tree determine the suction pressure in radial or deep bores in trunks.

A final record, especially pertinent to the question, was made on November 19, as the manuscript for this paper was being completed. Suction had come down to 0 with a rise of temperature from 7° to 18° C. in about 5 hours on the 15th, and several readings were made on the 19th, on which day the cool morning was followed by a warm clear mid-day without wind. Suction was equivalent to 9 mm. Hg. at $7^{h}30^{m}$ a. m., which was reduced and a pressure of +14 mm. Hg. set up in 4 hours, an increase to +15 mm. Hg. taking place by 2 p. m., at which time the outer layer of the trunk had a temperature of 22° C. These were the first positive pressures from a radial bore during the season.

At no time were any notable amounts of suction or pressure recorded by air-filled manometers (see record of oak, pp. 80, 81, and pine No. 6, page 36). An old radial bore from which gas sample had been taken 3 weeks earlier was emptied of mercury, cleaned and connected with an air-filled manometer on November 14. Within an hour a suction of −5 mm. Hg. was registered at a time when the radial bore was showing a suction of −8 mm. Hg. in a water-mercury filled instrument. At noon on this day (November 19) positive pressure had caused some air to escape, and at 2 p. m. a suction of −5 mm. Hg. was registered. The maximum suction registered by this radial bore was 92 mm. Hg. = 0.12 atm. at the end of August, after which time an irregular decrease followed, which on November 19 was transformed to positive pressure as noted.

### Suction in Short Stub of Branch.

Figure 16 B.

Stub of a branch 20 cm. long and 15 mm. in diameter at the cut end, arising from the trunk 25 cm. above the radial bore at an angle of 35° from it, was fitted with a manometer on June 19, while vigorous

growth was in progress. It is to be noted that such a structure communicated with the water-column under tension in the outer layers of the trunk and also with the air-filled wood of the interior. To what extent capillarity caused the central wood and disintegrating medulla to be filled with water could not be determined. It is obvious however, that the readings of this instrument would be the resultant of the tension on the water-column and of the expansion and contraction of the gas-filled wood. As in all preparations connecting with old wood, much air was drawn out from time to time. The amount of suction rose irregularly for 2 days, when air was released and the instrument reset to 0. An irregular increase carried suction to −93 mm. Hg. 4 days later. The mid-day decrease and nightly increase is plainly to be noted. On July 1 detailed readings showed suction diminishing to 0 at 10 a. m., being converted to a positive pressure of +3 mm. at mid-day, followed by suction reaching −26 mm. Hg. at 8 p. m. A similar variation was less marked on the following day which was equable and foggy. This type of variation was seen on several days following. High temperatures on July 11 lessened suction, producing positive pressure on the 12th and 13th.

After this time it would seem as if connection with the moving water-column under tension had been restricted, as in the following month the mid-day decrease with increase at night is discernible on 16 days—not more than one or two observations having been made on many of the other days. Similar records run to the close of the observations. Maxima of suction of −103 mm. Hg. June 19; 93 on the 27th; −36 on July 9; −48, July 16; −60, July 20; −71, July 24; −79, July 28; −83, August 2; −63, August 14; −75, August 19 and 20; −66, August 27; −81, September 2; −114, September 14; −134, September 24; −94, October 8; −123, October 18; −150, October 28; −160, November 5; −162, November 14, constituting a seasonal variation from high maxima in June, lesser maxima in July and August, and increasing maxima in September and October and November. The highest −162 mm. Hg. would be equivalent to 0.2 atmosphere. This suction was at the minimum temperature of 4° C., following a suction of −160 mm. Hg. on the previous day at a temperature of 6° C. The conclusion that temperature determining the volume and pressure of the gas in the vessels and old wood of the trunk is the principal factor in suction, and pressure of stubs of branches seems unescapable. The relation is even more clearly marked than in radial bores, although this may be partly due to the manner in which the instruments were fitted.

### Suction at End of Long Leafy Branch.

Figure 19 D.

A manometer was fitted by a clamped section of pressure tubing to the end of a leafy branch 4 meters long, arising from near the base of the trunk early in the season before growth had reached a maximum

rate. Much air was drawn out during the first week, after which an irregular increase in suction took place which reached a maximum of −84 mm. Hg. on June 17, when air was drawn out and the instrument was reset at 0. A maximum of 177 was reached on July 9, and suction varied about a high level until near the end of the month, when it was necessary to release air from the instrument and reset to 0. Suction varied below −174 for a month when air was released and the column set to 0. Then followed a period of wide variation below −108 mm. Hg. On September 9, near the end of the growing season, an irregular rise took place, which reached a maximum of −182 mm. on September 24 and −192 on September 29. The column was again reset at 0. The characteristic irregular increase in suction reached maxima of −267 mm. late in November.

If detailed daily records are examined, it is to be seen that not much variation took place on cloudy or rainy days. It is apparent, however, that suction sometimes decreased throughout the day, as illustrated by the records of June 13, 17, 22, 24, July 7, 11, 13, 14, and many others. The record of July 1 is a notable illustration of increase in suction accompanying a fog in the afternoon. Later in the season the cycle resembled that already described for the short stub of a branch, the maximum suction of morning diminishing to a maximum after mid-day, followed by a rise which continued until the following morning. This is well illustrated by the detailed readings made on August 27 and 28. Early in the season the variations were of a character implying that the tension of the water column in the conducting layers was an important factor affecting the resultant suction. Later the reactions seemed to be determined by the temperature changes in pressure and volume of the gases in the medulla and older wood. Suction at times amounted to 0.34 atmospheres.

### Suction and Pressure at Terminal or Distal End of an Excised Root.

A large root was cut at a distance of 1.6 meters from the base of the trunk and manometers attached to the exposed ends. This was not done until the season was far advanced (Aug. 22), and the growth period was coming to an end. The soil-moisture content was low and the leaves were taking a yellowish tinge. The preparation was one in which all parts of the hydrostatic machine were engaged. It is also to be noted that while the instrument would show the pull from the tension of the continuous water-column, lateral roots might furnish solutions to the main root, and endodermal action might well exert a pressure distally as well as toward and upward in the trunk.

The first reaction of the attached root was one of absorption and suction during the first 24 hours. Then followed a period in which positive pressure in the mornings was followed by suction after mid-day. The increase in volume of gases in the wood or increased

endodermal action might contribute to such a development of positive pressure through the old wood, while increased tension in the water-column would tend to produce a suction through the newer wood. The soil at a depth of 15 cm. under a carpet of grasses would not warm so rapidly as the trunk, in consequence of which the daily temperature effect would come later than in the stem. The latest pressure effect was at mid-day, October 10. Almost every clear day thereafter a suction diminishing toward mid-day and increasing toward and through the night was the customary occurrence. With the magnitude of pressures, which might be caused by osmotic action across the endodermis, unknown, it does not seem profitable to carry the analysis further. Positive pressures of +16 mm. Hg. were recorded when the test was first set up, some of +12 and +17 mm. (Sept. 2) were seen, while a pressure of −27 mm. was registered on October 4, and one of +5 mm. on October 13, which was the latest record of the season. Suction at times as high as −32 mm. Hg. was seen in August, but did not exceed −22 mm. during September. The range of variation became high in October, being from +5 to −45 mm., but thereafter fluctuated between −7 and −56 mm., variations of about the same range as in radial bores in the trunk.

## Suction and Pressure in the Separated Part of the Root.

The records obtained from the separated part of the root are of interest with especial reference to the fact that tension or pull from a column of water terminating in menisci in the leaves was eliminated. At the same time, the stoppage of the diffusion of material distally must have resulted in an abnormal condition to within a few days. These results are to be compared with similar measures on separated roots of *Pinus* (pp. 14–16).

In the case of the root of the pine, the stump of the separated root showed pressure of a kind that has been identified with the exudation of resin from ruptured canals and the contraction of living cells initially hydrated from the liquid in the bore. The root of the walnut developed a pressure of +156 mm. Hg. within 2 days, and exhibited diminishing pressures for a week. The balance varied from suction to pressure for a day, then suction prevailed to the end of the experiment late in November. The positive pressures were of a kind suggestive of possible hydration—dehydration cycle of living cells interrupting what may have been a continuous endodermal performance. Whether or not this performance would have been repeated if a section of the root had been cut away, as had been seen by many observers, is not known, but it is clear that deterioration of the terminal rootlets must have set in very soon after the initial operation.

Rising temperature appeared to cause increase of pressure in the initial stage, as would be the result in either endodermal or simple hydration reactions. Later, at a time when an unknown proportion of the root was dead, the familiar cycle of maximum suction in the morning, diminishing toward mid-day, and increasing with falling temperature was seen on clear days. This routine was disturbed on cloudy days or on days with a different course of temperature. Such reaction would seem to depend almost wholly on variations in volume of gases in the vessels and wood cells.

After extended records had been made the root was taken up (Nov. 20), revealing a surprising set of conditions. All of the rootlets were dead and the main axis showed evidences of disintegration to within about 30 cm. of the instrument. Here a short section of wood, of the color of "seasoned" walnut wood, terminated a section of the root, to the other end of which the manometer was attached. The woody cylinder was about 20 mm. in diameter and the bark 2 mm. in thickness. Both regions were high in moisture and apparently retained such proportion of living elements as give much the appearance of a normal root. The section protruded one-third its length from the sandy soil, and the remainder had no branches, or any absorbing organs. Exchanges could only go through the bark.

The uniformity of the records for September, October and November, and the condition of the root, support the inference that all of the root, except this 30 cm. section, died at the end of the initial period, and that for about ten weeks the measurements may be taken as showing the variations in volume of the gases included in the wood.

Positive pressures of +156 mm. Hg. were reached within 2 days of the beginning, and continued with diminishing value for a week, which probably marks the beginning of deterioration and exhaustion of carbohydrates. After this the short section of root-surviving, with its capacity for exchanges with the soil reduced to a very low rate, carried a stagnant water-column continuous with that in the connecting tube of the manometer. The variations recorded could only be attributed to changing volumes of gas under the influence of temperatures, which in this case were close to those of the soil. So clearly is the case as described, that the similarity of the variations to those in radial bores in the trunk may be taken as confirming in a very positive manner the conclusion that these variations are also due to changes in volume and pressure of gases in the central or older wood.

Finally, it is of interest to note that suction of −198 mm. Hg. = 0.26 atm. was measured, and that during the concluding period of the test suction ranged from 0.17 to 0.2 atmospheres. There being no intervention of tension in the water-column or anything but very slow exchanges with the soil, these amounts may be taken as expressing the actual conditions of gas-pressure in the section.

## DISCUSSION.

The conception of the hydrostatic system of the tree set forth in this paper includes a recognition of three regions mechanically distinct in the trunk. The first is a complete cylindrical shell of living cells in the cambial zone, through which nothing may pass except by diffusion through protoplasm. This layer is continuous with the endodermis in the roots and with the cells sheathing the conduits in the leaves. A second shell is formed by the water-column extending under varying tension from the menisci of the transpiring cells in the leaves downward through the recently formed conduits and wood-cells to the root-hair zones in the roots in a meshwork more or less complete. This shell occupies 2 or 3 layers of the trunk of the Monterey pine, including the outermost layers of the terminal parts of the shoot-bearing leaves. In the older central part of the stem, the tracheids contain air and would constitute a third component of the system.

That the two outer shells together form an effective enclosure is proved by the presence of gases in the older wood at pressures generally much lower than atmospheric, and with a composition widely different from that of the air. The most prominent feature is the increased partial pressure of the carbon dioxide, 600 times that of the air in trunks of *Juglans* in the autumnal condition, with a reduction of the oxygen to less than half its atmospheric proportions.

The cambium and the newly formed wood are subject to daily reversible variations in thickness which are associated with the balance between water taken in by the roots and loss from the leaves. Manometers connected with these layers by tubes filled with water show an increased suction under any set of conditions which would accelerate water-loss.

Recent measurements by Ursprung show that the suction force of the leaf-cells which constitute the upper terminal of the water system at mid-day may be double that shown in the morning. The graphs of daily variation of this feature of Bellis suggest a close correlation with variations in thickness of trunks and stems. Suction of 45 atmospheres was found in leaves of *Sempervivum tectorum* and in amounts in many other plants which would furnish ample force to move the column of water in stems at an adequate rate.[1]

No exudation pressure attributable to root action has been found in the pine. Positive pressures in bores made in the layers carrying the water-column are identifiable with the flow of resinous material from the canals and with the hydration-dehydration curves of parenchymatous cells in a cycle which come to an end within 3 days.

Exudation or positive pressure has been found in the massive cortex of cacti which is due entirely to the hydration-distention and

[1] Ursprung A. Einige Resultate der neusten Saugkraft Studien. Flora, 18–19, 566–599, 1925.

subsequent contraction of the living cells contiguous to the bore holes and hence coming quickly to an end.

These results are in agreement with the conclusions of Molisch, that exudation pressures are due to the action of cell-masses contiguous to cut surfaces or bore-holes.[1] Molisch, however, attributes exudation to traumatic reactions, or rather to the greater osmotic activity of callus or wound tissues, an interpretation not implied in my conclusions. My recently described experimental studies of absorption-swelling and contraction of living cell-masses has made it possible to give the specific explanation outlined in the preceding paragraphs.

The fact that Molisch observed positive pressures as high as 0.98 atmosphere in a section of a trunk of *Juglans regia* 130 cm. long and 12 cm. in diameter is fairly conclusive that exudation in the trunk can not be referred to root-action. This does not impair the conception of the endodermal mechanism cited elsewhere in this paper. Such an arrangement may be necessary to the production of pressures in roots as reviewed on the pages that follow.

It is evident that exudation might be produced in radial bore-holes by expansion of the central gas-body in the trunk. The possible participation of living cells in such action in such cases is not to be explained by wound-effects as proposed by Molisch or by absorption and dehydration as in *Carnegia*. Further detailed observations will be required in order to arrive at a full and adequate explanation of "root-pressures," especially as manifested in stems.

Some suction and some exudation pressures recorded by manometers attached to bore-holes or to stumps may be attributed to the expansion and contraction of the gases included in the central cylinder of older wood. The water introduced into a bore may be conducted by capillarity for a distance upward and downward in vessels and tracheids determined by the size of the conduits, resistance in perforations, and pressure of the gases with which these conduits were filled. No bore-hole has been made in any tree in these experiments in which dye was not conducted downward as well as upward from the cavity. The sugar maple can not profitably be taken as an example of a special class characterized by such conduction as suggested by Priestley and Wormall.[2] In the wood, downward conduction is a matter of the keenest interest at the present time, and it is conceivable that when an upward pull is exerted, as it is more or less constantly, on the cohesive meshwork of solution in the wood that it would tend to draw liquids into the region, and if the resistances were such as to give the readiest flow downward in some of these tracts a mechanism for carrying carbohydrates to the roots would be furnished. Ordinarily, however, experimental results can not

[1] Molisch, H. Ueber localen Blütungsdruck und seine Ursachen. Bot. Ztg., 60, 45–63, 1902.
[2] Priestley and Wormall. On the solutes exuded by root-pressure from vines. The New Phytol., 24, 24–37, 1925.

be so interpreted. Conduction of a dye or other reagent from a bore both upward and downward may be simply capillary conduction from a bore, mostly determined by gas pressures less than atmospheric.

The failure of a solution to move downward in a perforated stem may be due chiefly to the fact that no part of the system contains free gases or gases at less than atmospheric pressure.

Previously but little or no correlation has been found between the pressures registered by manometers inserted in various parts of a stem or trunk. No correlation would be possible unless it is known what regions of the hydrostatic system, as here described, were tapped. Suction and pressure are determined by different agencies in a tangential and in a radial bore, and by combinations of the two groups in stumps of branches, stems and roots.

It is obvious that a manometer attached to a stump will connect not only with the inner wood containing gases and the sap-column under tension, but also with the cortical layer through which air may pass. In actual practice when rubber pressure tubing is clamped over the end of a branch, stem or root, the outermost softer layers are crushed so that the cortex is sealed off, but this is not always the case. This uncertainty renders it difficult to interpret results which have been published from time to time, since it is not possible to identify the manometric connections established in the experiments.

The pressures at the cut ends of roots of the Monterey pine showed that the central body of gas was continuous in these organs as suction pressure was often lessened at times of high temperature, dominating or masking the pull from the leaves in the cohesive column of water, extending to the water in the bore. It is probable, however, that the newer wood in which this column extends is partially blocked by resin deposits near the surface of the cut which would lessen its effect. The action of resinous material was seen in a larger root where it exuded to an amount creating a positive pressure for a brief period.

Unknown disturbances of metabolism doubtless take place in a separated root. The initial exudation of resin may be held to account for positive pressures shown in the first 2 days of the test. That a slight positive pressure should again be shown, beginning 20 days later, is unexplainable, except in so far as it may be connected with the inactivation which followed. The death and consequent increased permeability of cells surrounding the resin canals and vessels would furnish material for such exudation.

The results of the tests of the roots of *Juglans* indicate a mechanism with some features essentially different. Chief among these is that of exudation pressure, recurring through long periods, at the end of a root from which the terminal section with its rootlets had been removed. The lateral branches of the root furnished endodermal mechanisms which might set up positive pressures in the parts of

the day in which water-loss by the leaves was least, but when the transpiration rate was highest the pull in the water-column equalized such root-action or exceeded it, thus setting up suction.

Late in the season, however, such endodermal action must be taken to have ceased with growth. It was seen that suction diminished in the warmer part of the day when included gases would show the highest expansion and pressure. In this stage, that is after the season of growth had ended, the roots of the pine and walnut showed suction variations of the same general character. The differences in action were manifested during the season of growth.

Separated parts of pine roots showed positive pressures, identifiable with exudation of resinous material from canals and probably contraction of living cells. A similar preparation of the walnut showed exudation of a type in which endodermal action and contraction of living cells may have contributed. Later the reaction was that of a shell containing gases, suction diminishing in the mid-day period, with expansion and increased pressure of the gases included. The attachment of a manometer to the stump or branch of a small pine tree connects the liquid of the instrument with the water-column as well as with the "gas chamber" of the interior. Capillary action and variations in the included gases determined the nature of the changes in all such cases.

The variations in *Juglans* in tests in which both the water-column and the gas-chamber were connected showed some noteworthy features. A short stub of a branch in which presumably the gas-filled center connected with the gas-body in the trunk, and the water-column was continuous with that of the trunk, showed a dominance of positive pressures at mid-day early in the season. It is not known if expansion of gas would contribute toward such results, whether or not a pressure actually in excess of atmospheric was present. It is probable, however, that the so-called "root-pressure" was a factor. After a mid-summer season, in which only suction was observed, positive pressures were again noted in November, not only in the stub but also in the radial and tangential bores. These positive pressures were at mid-day and at a time when the trunk was at its maximum temperature for the day, so that expansion of gases was doubtless an important contributory agent.

The records of a long leafy branch showed suction only, but throughout the greater part of the season a mid-day reduction was noticeable. The water-loss from the leaves on the dozen branchlets was at all times sufficient to balance any supply by "root-pressure," although the suction set up was diminished in the mid-day period at the time when included gases would be at their highest pressure.

Exudation pressures were a marked feature in the tangential bore in the height of the growing season and reached a maximum early in

the morning in this period, decreasing through the day as if expressing a balance between "root-pressure" and water-loss. The records bore this aspect until October, at which time a lessening of suction at mid-day was discernible and the course of variations was similar to that in the radial bore and in the branches. The accentuation of this condition followed, so that positive mid-day pressures coincidental with high temperatures of the trunk were seen in November.

It is to be noted that Molisch observed a morning daily maximum of exudation pressure in trunks of *Juglans*, *Æsculus* and *Betula*, with a diminution at mid-day, indicating that these records were made during the season of active growth and that the bore-holes were corrected with the ascending water-column under tension.

This feature of positive pressure after the close of the growing season was the only record of such pressures in the radial bore. Radial bores connect directly with the central gas-body and the pressures shown are obviously determined by changes in expansion and pressure determined by the temperature.

The difference between conditions in the central wood filled with gases and the outer wood carrying the sap-column under tension from leaf-action is well illustrated by the results of experiments described. A small pine tree which had been previously bored for some manometric measurements was cut down, the basal section including the bores removed and the freshly exposed basal surface quickly coated with stiff grease. A manometer was attached to a bore driven upward from this surface in the outer sap-filled wood and another to a similar bore in the older gas-filled wood. Suction in the last-named instrument rose slowly and to a lower maximum than in the instrument fixed to the outer wood, in which a continuous tension was maintained by pull from the transpiring leaves.

In fact in no adequate experiment did evidence fail to appear confirmatory of the conception of a gas-filled body of wood and outer, more recently formed tracheids and vessels in which a water-column existed under tension. The two regions are roughly separable in the pine where the sap-carrying tracheids contain but little air, and in which the rate of conduction is comparatively low. In dicotyledonous trees large vessels, which open into each other to give free conduits of great length, air is tapped by even the strictest tangential bores that can be made. It is notable, however, that in the autumn the outer wood, vessels and tracheids of dicotyledonous trees all tend to become filled with water according to Farmer.[1] In this condition the central gaseous cylinder would become as well defined as in the pines. The behavior of trees of the two types show suction, indicating

[1] Farmer, J. B. On the quantitative differences in the water-conductivity of the wood in trees and shrubs. II: The deciduous plants. Proc. Roy. Society B., 90, 232.

a similarity of relative arrangements of gas and water tracts late in the season.

The widely differing and partly antagonistic hydrostatic features of the two regions are so arranged as to render of no practical value the results of a great number of experiments in which pumps and gages are affixed to stumps of stems, branches and roots. Suction and pressures taken from both regions are the resultant of a number of agencies, the effects of which are not always capable of ready analysis. This view is based upon the results obtained from bores made in selected layers of pine trunks. Suction applied to the ends of such stems did not extract sap until after prolonged treatment and after more or less complete displacement of the air-body.

Suction of about half an atmosphere drew sap copiously from the outer layers of such stems in a few seconds. Dyes applied to the surface of the base of such stems move 4 to 15 cm. per hour, while such solutions might be drawn in a strictly limited tract at a rate over 90 cm. per hour, which probably represents a high normal rate in the intact trunks of pine trees.

Such experiments serve to demonstrate the high resistance to tangential and radial conduction, and the validity of the conception of a cohesive water-column. It is evident, moreover, that the samples of sap obtained in this manner may be taken to be nearly identical in composition with the solutions which reach the leaves in normal standing trees. The outermost layer of the pine with which no leaves are connected was invariably much higher in sugar (as glucose) than the sap-carrying layers. The solution passing upward to the leaves in the second and third layers of wood carried 0.13 to 0.16 gram per liter in June when the outer layer had a 0.27 gram per liter. Concentrations in both regions decrease rapidly when cut stems are allowed to stand, the content 2 days later being 0.05 and 0.06 gram in the sap-carrying wood and 0.20 gram in the outer layer. Sugars are seen to accumulate in the sap-carrying wood after the cessation of growth in August. A detailed series of analyses would probably show greater seasonal variation in the Monterey pine than is ascribed to evergreens by Dixon and Atkins.[1]

The ascending sap stream in the pine would contain 0.13 to 0.16 gram per liter glucose and also be highly charged with $CO_2$, as the innermost meshes of the water-column would be in contact with a central gas-body in which the partial pressure of $CO_2$ is about 200 times as great as in atmospheric air. Supplies of this amount might be of some importance in the photosynthetic activity of the leaf.

The meshwork sap-column of a composition as noted passes upward in vessels surrounded by sheaths of living parenchymatous cells,

[1] Dixon, H. H., and W. R. Atkins. On the composition of the sap in the conducting tracts of trees at different levels and at different seasons of the year. Notes from the Bot. School, Trinity Coll. Dublin, 2, No. 6, p. 335, 1916.

which usually contain more starch in dicotyledonous trees than in the pines or through the tracheids which are intimately interwoven with the tall flat rays comprising tracheids and living parenchyma.

The membranes of the pits between the two kinds of elements constitute actual openings through which plasmatic strands may pass. These strands soon disappear in maturing wood and thus make possible the continuous cohesive column of water in the wood of the conifers, in which movement as high as 96 cm. per hour has been set up by suction less than an atmosphere as noted in these experiments. A much higher rate would seem possible in the wood of the oak or walnut.

In any case the cohesive column may be visualized as filling a capillary tube with minute lateral openings into living cells, the colloidal mass of which is highly hydrated in a solution of sugars and salts with an osmotic value of several atmospheres. The colloids extend through the openings into the wood-cells. The suction power of these cells would absorb water to a point where it would be limited by the permeability of the plasma and stretched tension of the walls.[1]

It is not possible to make exact statement of the condition of the plasmatic strands in the perforations between the living cells and conducting cells, but it is obvious that any agency which would increase their permeability would allow water to be forced into the conduits, setting up a "root-pressure" in the water-column. An alternation of such action would furnish the pumping action upon which a pulsatory theory of ascent of sap has been based (see p. 195).

It is not clear how such alternation might be caused, nor has any evidence of such recurring activity been uncovered by the present experiments.

It has been found that, when a bore cuts the outer wood of a conifer, first water is drawn into tracheids and also absorbed to the limit of the suction power of living cells, registering suction in an attached manometer, after which increased permeability and escape of resinous material under pressure in ducts and canals sets up a positive pressure, which, however, soon comes to zero and the cycle is not repeated. Positive or exudation pressures may also be caused by expansion in the central gas-body, as has already been described.

While the observations presented were begun in 1924 and carried intensively through 7 months of 1925, the discussion of certain features is reserved until the records are continued over a longer period. The value of such extension is well illustrated by the work of Boehm[2] and of Molisch,[3] both of whom obtained high exudation pressures in dicotyledonous trees, in tests which covered more than one season.

[1] Ursprung, A., and G. Blum. Eine Methode zur Messung des Wand und Turgordruckes der Zelle, nebst Anwendungen. Jahrb. f. wiss. Bot., 63, 1–110, 1924.

[2] Boehm, J. Ueber einen eigenthümlichen Stammdruck. Ber. d. deut. Bot. Ges., 10, 539, 1892.

[3] Molisch, H. Ueber localen Blütungsdruck und seine Ursachen. Bot. Ztg., 60, 45–63, 1902.

## SUMMARY.

The principal results of the work described in the present paper are as follows:

1. The hydrostatic system of tree-trunks includes a central cylinder of old wood containing gases, a layer of new wood carrying the cohesive column of water, and a layer of living cells including the cambium.
2. The layer of living cells is impervious to gases except by diffusion.
3. The layer of recently formed wood filled with water is also impervious to a radial gas flow. The living rays pass through this region, the inner limits of which are not well defined.
4. The gases of the central cylinder in *Juglans* may include $CO_2$ at a partial pressure 600 times as great as in the atmosphere, with oxygen about one-half that of the atmosphere. Gases in the central cylinder of the Monterey pine include $CO_2$ at a pressure 200 times as great as in the atmosphere, with oxygen reduced about one-fourth. These disproportions are greatest under autumnal conditions.
5. Pressures in the central gas-body vary chiefly with temperature. Gages making air connections register pressures only slightly less than atmospheric in *Queraus, Pinus* and *Juglans.*
6. Gages connected with water-filled cavities may register suction as great as 0.5 atmospheres in which capillary entrance of water into vessels and tracheids is concerned.
7. Suction in the central gas-body is least at mid-day and greatest at daybreak in direct opposition to the course of water-loss and contraction of recently formed wood carrying the water-column.
8. Pressure in the water-column of a pine tree is always less than atmospheric in bore-holes after 2 or 3 days and the suction thus implied is greatest at the time of the highest water-loss, greatest contraction of the wood and greatest expansion of the central gas-body.
9. Positive or exudation pressure is seen in a pine trunk only during the first 2 days, and is to be attributed to the exudation of resinous material and contraction of living cells. Exudation pressures as high as 4 atmospheres have been recorded. No "root-pressures" have been found.
10. Positive pressures are manifested in bore-holes in the trunks of *Juglans* intermittently for many months, but are greatest in tangential bores and during the growing season. Positive pressures are also found in bore-holes penetrating to the central gas body after growth has ceased.
11. Exudation pressures are shown by severed roots of *Juglans* for a short time after separation. Exudation pressures over extended periods may be shown by the cut ends of roots with branchlets which may be connected with the action of these laterals.

12. Manometers attached to stumps of stems or roots by enclosing pressure tubing register a resultant of the action of capillarity of liquid used in making the connection, the variations in volume of the central gas-body, and of the tension in the cohesive column of water in the wood. In some instances connection is made with outside air through the cortex.

13. The results of experiments in which suction or pressure is applied to the entire cross-section of a large stem are complicated and not easily to be analyzed.

14. Suction applied to an entire pure trunk is not followed by sap extraction until the end of a period which may be as long as one or two hours.

15. Suction of 0.5 to 0.24 atmosphere, applied to water-carrying layers of Monterey pine, extracted sap within a few seconds.

16. Suction as above applied to an entire pine trunk caused a slight acceleration of the rate of movement of fuchsin in the water-carrying layers, in which the dye usually moves 4 to 15 cm. per hour.

17. Suction, as above applied to newly formed wood of the pine trunk, caused solutions of dye to move at rates as high as 96 cm. per hour. It is assumed that a sap solution would be carried farther in the same period.

18. Suction applied to bore-holes in the ends of trunks caused dye solutions to be drawn through the stem in limited tracts leading to the bores. Manometer tests showed but little effect tangentially away from the conduits engaged.

19. The sugar (as glucose) content of sap is greater in the outer layers than in the inner layers carrying the sap-column of the pine. The proportion of sugar present is high in the spring, is reduced during the growing season and increases after wood formation has ceased.

20. Upwardly moving columns of water in the Monterey pine occupy the layers connected with the leaves. The wood of the terminal internode and of the second, third and fourth layers of older nodes are so connected. The nature of the movement in the outermost layer of wood was not determined.

21. The downward movement of solutions from a bore in a trunk was seen in the pine, walnut and oak. Such a movement is not a special characteristic of the maple. The action in question seemed to be due to capillarity.

22. Positive or exudation pressures in the cortex of the tree-cactus are due to absorption of water and subsequent contraction by living cell-masses. Such action may also occur in *Pinus*, but the principal factor in this tree is the discharge of the resin-canals. The duration of positive pressure in both cases is limited to the first few days after a bore hole is made.

23. Exudation pressures in *Juglans*, attributable to the action of living cells and with a maximum at dawn and minimum at mid-day, occurs in the new wood of *Juglans* and has been observed by Molisch in sections of trunk standing in water. These pressures are therefore not to be connected with "root-pressure."

24. Positive pressures in bore-holes and stubs of branches after the cessation of growth are coincidental with temperature expansion of the central gas-body in *Juglans*. Such pressures reach a maximum at mid-day and a minimum in the morning, or at the time of lowest temperature.

25. No positive or exudation pressures in the trunks of *Carnegiea, Pinus, Juglans* or *Quercus* have been observed which can be positively connected with osmotic pressures set up in the root-systems. Exudation pressures in roots of *Juglans* which have been recorded may be due to osmotic action of the endodermal mechanism. The existence of such a connection remains to be established.